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COUNCIL ON COMPETITIVENESS

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A COMPETITIVE PROFILE OF THE
AEROSPACE INDUSTRY

Research Paper for

GAINING NEW GROUND:
TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future.*

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling.

SECTORAL PROFILE: AEROSPACE INDUSTRY

SUMMARY

Key Points:

- The aerospace industry is comprised of a few large integrated producers that draw from an extensive, varied, and increasingly international supplier base.

- Aerospace has run consistent trade surpluses in the post-World War II period. 1989 was another record breaking surplus year at $22.1 billion. Civilian aircraft-related exports have been particularly strong in the current business cycle, whereas the declining emphasis on military products has signaled less robust demand in that sector of the industry.

- Aerospace is the user/driver of multiple advanced product and process technologies. The industry also draws on a broad variety of basic goods and services.

- The aerospace industry is both capital and R&D intensive. In 1989 aerospace R&D funding was $24.3 billion, the highest of any industry in absolute terms.

- The magnitude of risk and enormous staying power required until break-even distinguishes commercial aviation from virtually any other industry.

- Aerospace makes up the largest sector of the defense industry. Recent cuts in the defense budget have decreased demand for aerospace products, and an anticipated further decline in defense spending is expected to signify major structural shifts in the aerospace industry.

- There is increasing divergence between defense and civil aerospace technology needs, resulting in a major decrease of military to civil technology transfers. While civil aerospace focuses on efficiency and safety, the military has emphasized ultra-high performance.

- Foreign producers are becoming increasingly competitive with U.S. firms and are gaining market share in both intermediate and final aerospace products. The U.S. share of world markets in aerospace products declined from a high of 79 percent in 1970 to 62 percent in 1988. Airbus Industrie has made significant inroads into the world market for commercial jet transports, as a result of foreign government support programs, including extensive subsidization of development costs.

- U.S. component and subsystem contractors -- the backbone of the aerospace industry -- are also affected by foreign competition. Their viability is directly affected by subsidization of development and production.

- As the costs of developing and commercializing new aerospace products have increased, there have been more efforts at international collaboration.

Factors Supporting the Competitiveness of the U.S. Aerospace Industry:

- High levels of R&D spending.

- Superior systems-integration capabilities.

Factors Weakening the Competitiveness of the U.S. Aerospace Industry:

- Foreign government targeting and subsidies.

- Weakness at the technology validation stage of the R&D process.
- Fiscal and monetary policies that inhibit long-term investment.

- Anti-trust policies that inhibit intra-industry interaction.

- Uncertain supply of qualified engineers and/or technicians.

Insights from the Aerospace Industry for the National Technology Strategy:

- Strong capital investment and R&D spending are critical to the success of innovative, high tech industries.

- When industries are knowledge- and capital-intensive, have high barriers to entry and are critical to national prestige and defense, foreign governments will support their development. U.S. government policies should take this reality into account.

- First-rate regulatory agencies are often key to an industry's competitiveness.

- Technology transfer from the military to the civilian sector is no longer as relevant as it once was, given diverging mission requirements.

- A strong, consistent, cost-effective and innovative supplier base is vital to original equipment manufacturers.

- Trade policy should recognize and support continuing industry access to foreign markets, which account for almost sixty percent of total sales.

- High tech industries, such as aerospace, yield broad, cross-cutting economic benefits to the nation.
- A sufficient source of well-trained scientific, engineering, and technical personnel is essential to the success of high tech industries.
- The aerospace industry has been weak at the technology validation stage of the R&D process because of policies that have encouraged a clear separation of government and industry roles.

Critical Technologies:

- Advanced Composite Materials
- Advanced Sensors
- Aerodynamics
- Airbreathing Propulsion
- Artificial Intelligence
- Computational Science
- Optical Information Processing
- Rocket Propulsion
- Software Development
- Superconductivity
- Ultrareliable Electronic Systems
- Very Large Scale Integrated Circuits

I. STRUCTURE OF THE INDUSTRY

Basic Information on the Industry

Definition:	The Commerce Department's "Aerospace Industry" basically includes those industries in SIC categories 372 and 376: Aircraft (3721), Aircraft Engines and Engine Parts (3724), Aircraft Auxiliary Equipment, n.e.c. (3728), Guided Missiles and Space Vehicles (3761), Space Propulsion Units and Parts (3764), and Space Vehicle Equipment, n.e.c. (3769). To a lesser extent, aerospace also includes Radio and Television Communication Equipment (3663); Search, Detection, Navigation, Guidance, Aeronautical Systems, Instruments and Equipment (3812); and Measuring and Controlling Devices, n.e.c. (3829).[1]
Total Sales:	(1989) $117.6 billion[2]
Employment:	(1989) 1,321,000[3]
After tax profit:	(1989) 3.3% of net sales[4]

Key Segments of the Industry

The industry can be described in terms of a three-tiered supplier network pyramid[5] that includes about 15,000 companies in the United States. [See Figure 1.] Airframe Assembly and Sales is the end-category. On-Board Avionic Systems; Propulsion Systems; and Airframe Structures, Subassemblies, and Subsystems as suppliers to Airframe Assembly make up the next tier. On-Board Avionics are in turn fed by Electronic and Electrical

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[1] Aerospace Industries Association, *1990/1991 Aerospace Facts and Figures* (Washington, DC: Aerospace Industries Association of America, 1991)

[2] Ibid.

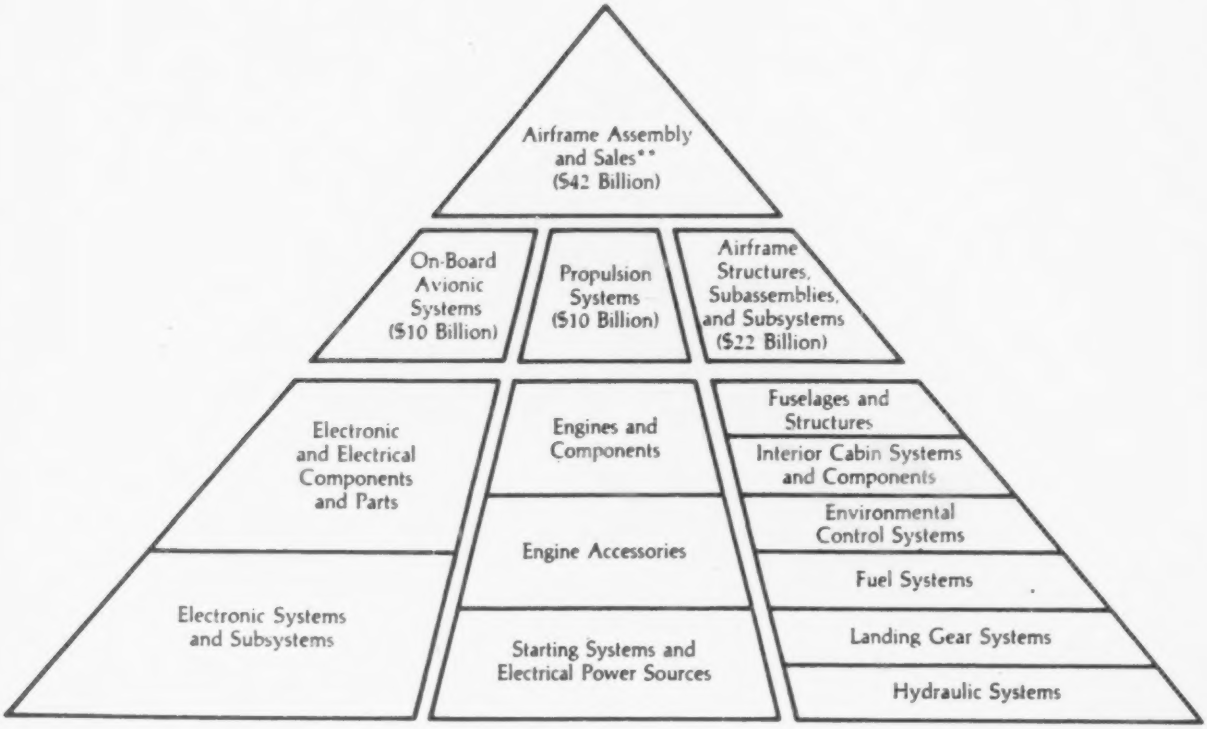
[3] Ibid.

[4] Ibid.

[5] SRI International, *Changing Markets for Aircraft Products*, Report No. 740, Fall 1986.

Figure 1.

The Aircraft Industry Pyramid*


Airframe Assembly and Sales** ($42 Billion)
On-Board Avionic Systems ($10 Billion)
Propulsion Systems ($10 Billion)
Airframe Structures, Subassemblies, and Subsystems ($22 Billion)
Electronic and Electrical Components and Parts
Electronic Systems and Subsystems
Engines and Components
Engine Accessories
Starting Systems and Electrical Power Sources
Fuselages and Structures
Interior Cabin Systems and Components
Environmental Control Systems
Fuel Systems
Landing Gear Systems
Hydraulic Systems

Source: SRI International, *Changing Markets for Aircraft Products*, Report No. 740, Fall 1986.

*This pyramid illustrates three layers of the complex structure of the aircraft industry, which includes about 15,000 companies in the United States.

**1984 sales.

Components and Parts, and by Electronic Systems and Subsystems. Propulsion Systems are fed by Engines and Components, Engine Accessories, and Starting Systems and Electrical Power Sources. Airframe Structures are fed by Fuselage and Structures, Interior Cabin Systems, Environmental Control Systems, Fuel Systems, Landing Gear Systems, and Hydraulic Systems.

Size Distribution of Companies

The aerospace industry is highly concentrated at the top by original equipment manufacturers (OEMs) representing basic aerospace product sectors of aircraft manufacture (52 percent of 1989 revenues), space (22 percent) and missiles (9.5 percent). Related products and services account for the remaining 16.5 percent of 1989 revenues.

The orginal equipment manufacturers are supported by about 15,000 U.S. supplier companies, as well as increasing numbers of foreign-owned firms. Sectors, such as aircraft or missiles, can be described in terms of a pyramid with final assemblers such as Boeing, Lockheed, or McDonnell Douglas at the top. In the case of aircraft manufacturers, the pyramid then breaks into three basic areas of supply required in aircraft manufacture: avionics, propulsion, and subassembly/subsystems. Suppliers of these major components, in turn, draw upon lower tiers of companies making up the bottom half of the pyramid. In 1989, about 10,000 supplier firms, for example, provided engines, sub-assemblies, components and parts for civil aircraft.[6]

U.S. aeropace continues to lead the world in complex systems integration required for its principal product sectors of civil aircraft, military aircraft, missiles and space. However, even in areas of traditional superiority, the industry faces an increasing global challenge as more countries develop highly proficient and competitive aerospace capabilities.

Market Segments

Civil Aircraft

The civil aircraft sector breaks into three areas: 70 plus seat commercial transports, general aviation (including everything from single-engine planes to multi-engine commuter planes not exceeding 33,000 pounds), and helicopters. Civil aircraft accounted for 19 percent of total aerospace sales in 1989.[7]

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[6] Wilbur Smith Associates, *Economic Impact of Civil Aviation on the U.S. Economy*, 1990, p. 15.

[7] *1990/1991 Aerospace Facts and Figures.*

The large commercial transport producers for the United States are Boeing and McDonnell Douglas. A third builder, Lockheed, gave up the business after incurring financial difficulties with its L-1011 program. Boeing is the world leader in large commercial aircraft sales and remains in control of over half of the world market. McDonnell Douglas has recently been ousted from second place by Airbus. At year-end 1990, the world backlog of 1069 large transport units on order totaled $81.4 billion in value. Boeing accounted for 51 percent of the units and 62 percent of the backlog value. Airbus is credited with 24 percent of units (21 percent of value) and McDonnell Douglas had 18 percent of the backlog units and 15 percent of the total value. Boeing with its dominate market position, is also the nation's leading exporter with 60 percent of its production headed to overseas customers.

The United States has 11 producers of aircraft in the general aviation category. These firms shipped 1,535 aircraft in 1989 worth approximately $1.8 billion. The United States also has six civil helicopter producers. In 1989, these firms produced 515 units worth about $215 million.

A recent study of civil aircraft manufacturing in the United States determined that in 1989 the 19 civil assembly companies noted spent $21.2 billion of which 92 percent was spent in the United States. Combined, the three categories of U.S. civil aircraft, engines and parts registered $25.6 billion in export sales for 1989 -- roughly 80 percent of U.S. aerospace exports for the year.

Aside from airframe manufacturers, a second significant OEM category pertinent to both military and commercial aviation is engine-producing firms. There are three principle engine suppliers for large commercial aircraft. United Technology Corp.'s Pratt & Whitney division leads the field, followed by General Electric and Rolls-Royce, LTD. Other smaller international players, however, are developing engine production capabilities. This is a trend which will likely bring about an increase in the number of joint-ventures in the engine field. SNECMA/GE is an example of such a cooperative arrangement, as is the Pratt & Whitney, Rolls-Royce, Japanese Aero Engines, MTU and Fiat Aviazone International Aero Engines venture.

Military Aircraft

Military category aircraft sales of $38.9 billion accounted for one-third of total U.S. aerospace revenues in 1989.[8] Commercial jet transport producers (Boeing and McDonnell Douglas) also have separate business units devoted to military aircraft and related systems. Other key producers include Northrop, General Dynamics, and Rockwell. Conversely, the latter companies also maintain separate production facilities and business units supporting their commercial aircraft business.

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[8] *1990/1991 Aerospace Facts and Figures.*

Missiles

U.S. missiles system development involves the aforementioned firms, as well as a number of other U.S. aerospace firms, as major contractors and suppliers. The prime missile producers are supported by major systems contractor specialists that provide propulsion systems, guidance, flight control, and necessary communications associated with specific missiles. Such avionics suppliers represent a cross-section of high tech electronics and computer companies. Missiles sales accounted for $11.2 billion in 1989.[9]

Space

Space products accounted for $25.8 billion in sales in 1989.[10] The national space program draws on systems integration and supplier capabilities that are similar to the skill base supporting aircraft and missile categories. Much of space is defense-related. General production categories include spacecraft and satellites, launch vehicles, space and ground networks, communications and data systems.

Relationship between National Defense and the Aerospace Industry

In the post-World War II period, the world's civil aircraft industry benefited from military aircraft innovations. Some of the best examples are swept wing and jet engine technologies that were incorporated into the first generation of civil jet transports. However, this early relationship has changed over the years:

- Direct military to commercial transfers have declined during the past 20 years with a divergence in mission requirements.[11] Some would refute this assertion by citing the potential for commercial transfer in DOD's air-breathing engine improvements program and DOD's aerospace plane program. Nonetheless, the military has focused increasingly on ultra-high performance, whereas the civil industry has emphasized reliability, safety, maintainability, and economy over an extended period of time.

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[9] *1990/1991 Aerospace Facts and Figures.*

[10] *1990/1991 Aerospace Facts and Figures.*

[11] Artemis March, "The U.S. Commercial Aircraft Industry and its Foreign Competitors," *The Working Papers of the MIT Commission on Industrial Productivity, Vol. 1* (Cambridge, MA: The MIT Press, 1989), p. 16.

- Different mission requirements appear to be re mount of generic technology validation useful to commercial pr Validation is the lengthy and expensive process by which generi r subsystems are tested under actual or simulated operating co as to understand their performance limits and risks.)[12]

- Shrinking military contracts and funding incenti he ManTech and IMIP programs[13] and restrictive governr ed ceilings on reimbursement for defense-related IR&D have a pen private sector aerospace capital investment and R&D funding. ducers have been more affected by these changes than the airfran engine producers had received substantial reimbursements. V ry-to-commercial transfer is already marginal, the contraction financial support contributes even further to the decline of such

Relationship to NASA

NASA maintains both civil and military aerospace inte the past 25 years, NASA has increasingly emphasized space over aviation. NAS ide direct funding for some research in civil aviation, but NASA's focus is eneric technology research and not product development. NASA contracts, fo ave accounted for less than 5 percent of Boeing's commercial R&D over the ars. Boeing and McDonnell Douglas' effort to look at key technologies and mic viability of a high-speed civil transport is an unusual example of a NASA- aircraft project.

Most space industry output is government-contracted, of this is, in turn, defense-related. The DOD-NASA relationship is apparent quency of military payloads on Shuttle missions or the interchangeable use of NA e military facilities and testsites for missile development and trial deployment. d DOD also have significant data exchange on weather, communications, and , especially where NASA and DOD employ different types of operational satel er data.

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[12] Ibid., p. 16-17.

[13] ManTech and IMIP are the DOD's Manufacturing Technology and dernization Incentives Program, in which DOD provides capital investment to industry.

Key Relationships with Other Industries:

The U.S. aerospace industry is a major purchaser of goods and services. Aside from purchases of electrical machinery, primary and fabricated metals, chemicals, and other transportation equipment, the aerospace industry's demand for business services, retail, foods and beverages, utilities, real estate and health services, is considerable.

Aerospace is traditionally regarded as a "trickle down" industry, which is one of the reasons it is regarded as both a prestigious and strategic sector of the economy in developed and developing countries alike. As a "pioneer" industry, aerospace is a driver of technology. Its innovations have often generated lower-cost adaptations for other product markets, benefiting the entire economy. Some concrete examples include turbochargers, fiber-reinforced plastics, and computer-aided design and manufacturing (CAD/CAM).

There are numerous direct and indirect spin-off applications from aerospace technology in the areas of health and medicine, capital equipment production, energy, industrial productivity, safety and the environment, transportation, construction, consumer/home/recreational products, digital image processing, computer processing and technology, and communications.[14]

Regulations

Because the government is a primary customer -- largely through the Defense Department and NASA -- aerospace is one of the most regulated of industries. How aerospace does business is governed by literally thousands of statutes and by the extensive Federal Acquisitions Regulations, supplemented by directives, instructions, procedures, manuals, reports, management systems, and data requirements. The government keeps close control of the industry at every step of the contracting process, including how much profit can be earned on government work, and what costs may be considered allowable (charged to the government).

Commercial aircraft manufacturing is regulated primarily by the Federal Aviation Administration's airworthiness requirements, which are designed to ensure public safety.

In addition, there are environmental regulatory limitations such as the Stage 3 noise regulations.

Export controls define which aerospace products or technologies can be exported and to which countries they may be exported. Because exports are a large and growing component of the U.S. aerospace business, export controls can be burdensome. This is especially true if imposed unilaterally by the United States and not by other countries, or if they restrict sales of products available from competitor nations.

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[14] AIA, *Technology Diffusion – The Movement of Technology Between Aerospace and Other Industries*, (Washington, DC: Aerospace Industries Association, October 1985), p. 8.

Competitive Position of Aerospace

Trade

U.S. firms commercial aircraft firms have dominated the aerospace industry since World War II. Boeing commercial aircraft alone accounts for about 2 percent of U.S. export revenues. The aerospace industry is the leading exporter among U.S. manufacturing industries and has consistently run surpluses in the post-war period.[15] Aerospace exports totaled about $32.1 billion in 1989, for a $22.1 billion U.S. aerospace trade surplus. Export volume is three-quarters civil products and one-quarter military, with a recent over-all trend showing declines in military exports and increases on the civil side.

The principal customers for U.S. aerospace exports are the United Kingdom, Japan, France, Canada, Germany, Australia, and Brazil.

Aerospace has a strong position in world markets, but its share is shrinking because of increased foreign competition. Between 1970 and 1988, the U.S. share of world aerospace markets declined from 79 percent to 62 percent. Heavy defense spending in the early to mid-1980s pushed U.S. world market share up to 73 percent in 1985, but the more recent decline in DOD spending coupled with increased foreign spending has resulted in the shrinking of U.S. percent of world market share.[16]

While global production of both final products (complete aircraft, engines, spare parts) and intermediate products has increased, the number of U.S.-based suppliers has shrunk dramatically, despite a booming market. U.S. exports of aerospace parts are still more than triple the value of parts imported, but in recent years, parts imports have been rising relatively more rapidly.[17]

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[15] *1990/1991 Aerospace Facts and Figures.*

[16] *1987/1988 Aerospace Facts and Figures*, p. 15; *1983/1984 Aerospace Facts and Figures*, p. 15; and *Facts and Perspectives*, June 1988, p. 1; Aerospace Industries Association, Washington, DC.

[17] *1990/1991 Aerospace Facts and Figures*.

Growth and Profits

Despite occasional cyclical downturns, aerospace has been one of America's most successful enterprises. It is healthy and profitable. Aerospace sales reached about $117.5 billion in 1989. As an industry, aerospace is profitable. Profit as a percent of sales is, however, less than for all manufacturing and has consistently been so.[18]

Despite a slow-down in defense spending and the reduced demand for military aircraft, aerospace is booming because of strong commercial demand. Trade in commercial jet aircraft, sub-systems and components has surged. According to major aerospace company reports to the Bureau of Census, the U.S. aerospace industry's total backlog reached $191.5 billion in 1988.[19]

Outlook

After record spending in the early and mid-1980s, demand for military aircraft contracted by about 25 percent in the late 1980s, according to some sources. Impending cuts in the defense budget will probably mean even further reductions in demand for military aircraft, missile systems, and military space projects. Research and production may, however, continue in small, agile tactical planes that incorporate technologically advanced equipment.[20] Defense lines may be kept busy through modernization of existing aircraft with up-to-date electronics and some major new projects, including the Advanced Tactical Fighter, the Advanced Tactical Aircraft, and the LHX helicopter. Further down the road, the defense community has set its hopes on the Aerospace Plane (Transatmospheric Vehicle).

Demand for commercial aircraft is likely to continue to rise. Air travel is expected to double by 2005. The market could see between 9,600 and 9,900 aircraft deliveries between now and 2005.[21] The market for new planes over the next 15 years is expected to average $38 billion a year, compared with $14 billion a year from 1970-89. A change in the political climate may also create market opportunities in Eastern Europe and other centrally planned economies.

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[18] *1990/1991 Aerospace Facts and Figures*.

[19] Bureau of the Census, *Aerospace Industry (Orders, Sales, and Backlog)*, Series MA37D (Annually).

[20] AIA President Don Fuqua in "AIA Predicts Gradual Downturn, Shift to Civil Technologies for Defense Industry," *New Technology Week* (Dec. 18, 1989), p. 2.

[21] Don Fuqua in *New Technology Week* (Dec. 18, 1989), p.2.

Despite increasing demand, however, to meet the foreign challenge the U.S. aerospace industry will need to develop competitive new products. Launching a new generation of commercial aircraft costs $2 to $4 billion, and a company must sell roughly 600 units to break even. Developing a new engine costs $1 to $1.5 billion and requires sales of 2,000 units to break even. The industry estimates that break-even occurs after 14 years for a new aircraft and after 10 years for a new engine. These slow rates of return can be prohibitive. Foreign producers, often assisted by supportive governments, do not have the burden of such high risk.

New efforts at commercialization of the space industry could signify an upward trend in this area. However, high costs and a vaguely defined national space policy have tended to deter commercialization.

Trends

The market for commercial aircraft is expected to expand through the mid-1990s. The future of defense aircraft production is less certain.

Foreign competition will increase. Developing countries, such as Brazil and Indonesia, perceive aerospace as a strategic and prestigious industry that serves as a major technology-driver for the rest of the economy. Furthermore, the Europeans and, more recently the Japanese, have been building up their respective technological capabilities. The Europeans, in particular, have a competitive position in the market.

Currently, the U.S. commercial jet transport aircraft industry's chief competitor is Europe's Airbus-Industrie, which has been marketing its products aggressively. Airbus has been successful in selling its A-320, as well as programs such as the A-330 and A-340. Airbus is now contemplating development of a 600-seat aircraft. The development of Airbus' full family of aircraft has been facilitated by extensive government support.

A further challenge comes from (the almost entirely government-funded) French Aerospatiale, Deutsche Aerospace, and (the now private) British Aerospace. They have recently announced plans to study a more commercially viable, next-generation Concorde that would feature an approximate doubling of both distance capability and speed, as well as offering significant fuel and noise reduction.

The Japanese represent a more long-term challenge. They are currently attempting to establish links with both the American and the European aerospace industries, presumably to move up the learning curve in terms of both technology and marketing. The recent Mitsubishi-Daimler Benz pact is one such arrangement. Although it would be somewhat premature to speculate, the Japanese may be gearing up for a future in aerospace that will leapfrog over current technology. In commercial aircraft, they have directed their efforts at hypersonic and supersonic trans-Pacific capability. Estimates for production of such a product range from 10 to 15 years. In the more near-term future, the Japanese will be active participants in the market -- in engines, subsystems, and parts -- and will probably draw heavily on their electronics and materials expertise. The Japanese will be part of various cooperative agreements and will undoubtedly have a growing presence in the space market.

In general, the key to obtaining market share in the next century will be in creating competitive new products that incorporate efficiency-, safety-, and performance-improving technologies. The U.S. industry's ability to do this in the face of continued subsidization of Airbus is a major question.

Dual use technologies are becoming increasingly important in the aerospace industry. This has come about through a variety of reasons: National defense budgets are now largely devoted to gathering and processing information; improving communications on the field of battle, as well as worldwide; and testing and supporting complex military equipment. Because military systems are often produced in many countries, using imported materials, components, and software -- many of which are based on civil products and technology -- the distinction between military and civil use has been blurred. This is likely to continue as collaboration increases, as defense budgets decline and military planners look for ways to get the most from research and development and procurement dollars. In the United States, as in Europe, there is growing interest in buying commercial products "off the shelf" for defense applications, where possible. This will further contribute toward a graying of the line between civil and defense technology.

Internationalization

In response to the rise in foreign technological innovation, the imperative of retaining marketshare, and in some cases, obtaining needed financial backing, U.S. original equipment manufacturers like Boeing and McDonnell Douglas have adopted an increasingly global production strategy.

1. Licensing and Foreign Direct Investment

U.S. primes have engaged in various forms of foreign partnership. Licensing has been used extensively by U.S. manufacturers. Know-how, patents, or trademarks are transferred in return for licensing fees or royalties, which help offset the high cost of research and development. Licensing is an arrangement that has been used in military aircraft production. U.S. aerospace foreign direct investment is still marginal with isolated examples primarily in Canada and Europe. There has been no need for an off-shore transfer of aerospace capabilities. In some instances, U.S. labor is actually cheaper than labor in competing countries; industry productivity has been high. The complex nature of aerospace products allows original equipment manufacturers to purchase systems or components offshore when and where desirable. The OEMs are essentially systems integrators, and the United States still retains a technological edge in this capability.

2. Foreign Suppliers and Off-sets

Nonetheless, while OEMs themselves have not moved off-shore, parts and subassemblies are coming from abroad with increasing frequency. In many cases these are simple business decisions, reflecting a need for cheaper subcontracted parts than are available domestically. In the case of defense aircraft production, there are often elaborate offset arrangements which are designed to gain OEMs market share.

It has been argued that it will not be the primes so much as domestic subcontractors that will be the big losers in the aerospace shake-out. The number of U.S.-based suppliers has shrunk dramatically, despite a booming market. Mostly, this has come as a result of increased competition. In the case of defense aircraft production, procurement policy has limited profits and cash flow as well as the allowability of independent research and development (IR&D) spending; the result has been a squeezing of investment and a reduction in competitiveness.

3. Civil and Military Joint-Ventures

Joint ventures are very attractive because they may be designed so that both costs and risks (for equity investments, research, and product development) are shared, as well as providing market access. The integrated producers argue that the era of a U.S. monopoly in aerospace is over and that the industry can no longer operate in isolation. If Boeing doesn't make a deal with the Japanese, Airbus-Industrie will. While certain technologies should remain secret, select process and material exchanges can benefit the industry as a whole. It is also argued that because it is the Japanese and the Europeans who are the biggest purchasers of U.S. products, cooperative agreements are a logical way to gain market access.

On the other hand, some have expressed a fear that the big producers are entering into Faustian pacts -- selling core technology in exchange for market share. These critics argue that once competitors have the technology, they will leave U.S. producers behind.

International collaboration is becoming increasingly prevalent. Some examples of international partnerships in which U.S. firms are involved include the Boeing 767 jet aircraft project. Japan Commercial Aircraft Corporation (Japan) and Aeritalia (Italy) are major subcontractors to Boeing. CFM International is a joint venture with General Electric (U.S.) and SNECMA (France) to build the CFM56 jet engine. International Aero Engines involves the construction of V2500 jet engines by Pratt & Whitney (U.S.), Rolls Royce (U.K.), Japanese Aero Engines Corp. (Japan), Motoren-und-Turbinen-Union (Germany), and Fiat Aviazione (Italy). A fourth example involves GE and Rolls Royce for production of each other's engines (the GE CF6-80C2 and the Rolls Royce RB211-535E4).

Defense aerospace cooperations have tended to move increasingly away from mere licensing or coproduction arrangements to joint ventures, but defense cooperation has not proceeded at the same pace, or as successfully, as cooperation in the civil sector. There have been outstanding success, and cooperation will undoubtedly continue, but the failure or poor performance of some programs, a shrinking defense market, and technology transfer concerns, indicate a continuing rocky road for partnerships in this sector of the industry.

Restructuring

On the micro level, individual firms have made several changes to meet increased competition.

In general, major U.S. firms are in the process of reorganizing their operations. There have been great efforts to step up early manufacturing involvement in the design and development process and to initiate new processes, automation, and computerization. Finally, airframe and engine companies are pressing their suppliers and subcontractors for higher quality and at reduced costs. They are also working more closely with customers to design and develop transports that best meet airline passenger needs.

II. IMPACT OF TECHNOLOGY IN THE INDUSTRY

The fact that the U.S. aerospace industry has historically maintained high levels of R&D spending gives some indication of the significance of new technology to the industry. In 1989, R&D expenditures totalled $24.3 billion.

Innovation has traditionally come both from the supply and the demand side. Acting as a kind of "supply-side" push, U.S. aircraft companies have had a strong tradition of commitment to their products and the continued need for innovation.

For most of the post-war period, a strong customer base had backed producers on the "demand side." The demand pull from customers originally came from three sources: civil regulators, commercial airlines, and the military.

- CAB regulation prevented price competition and focused on performance competition instead. Manufacturers were able to push the costs of adding new technology through to the customer via CAB-approved fare increases. With deregulation, this cost-transferral to the end-user was lessened. Deregulation did, however, perhaps contribute to some improvements in cost efficiency.

- The major American commercial carriers often prompted and supported the development of new aircraft products (e.g., Pan Am which encouraged production of the first commercial jet, new engines, and the 747). Airlines employed their own teams of engineers who worked closely with aircraft and engine manufacturers in product development. After deregulation, the airlines took a less technical, more business/profit-directed approach which weakened this close R&D working relationship. The rise of leasing companies (now representing over a third of all new jet orders) has also added to an increasing focus on profits, placing the onus for technology development and funding on the manufacturer.

- Military demand for performance pushed the development and early application of many technologies (e.g., jet engines), as well as providing the test beds for the technology used in early commercial jet aircraft.

Critical Technologies

The U.S aerospace industry has identified the following technologies as critical to maintaining the industry's international competitiveness:

Advanced Composite Materials
Advanced Sensors
Aerodynamics
Airbreathing Propulsion
Artificial Intelligence
Computational Science
Optical Information Processing
Rocket Propulsion
Software Development
Superconductivity
Ultrareliable Electronic Systems
Very Large Scale Integrated Circuits

In the following section, each of these critical technologies is assessed in terms of the current U.S. position relative to its chief competitors.

CRITICAL TECHNOLOGY: Advanced Composite Materials

DESCRIPTION: Advanced composite materials are high-performance, environmentally durable advanced materials. They include metal matrix, ceramic matrix, carbon/carbon, resin matrix, and hybrid composites.

WHY IS IT A CRITICAL TECHNOLOGY: These materials represent the potential for major improvements in the integrity of aerospace structures, including both high-speed aircraft and missiles (supersonic and hypersonic), high temperature engine components; and ultralightweight structures. Lower structural weight translates into true performance enhancements: increased range, payload, velocity, or maneuverability. High performance composites will provide advanced aircraft competitiveness.

U.S. POSITION RELATIVE TO RoW: Due to a strong demand for advanced composites from the aerospace industry, the United States is generally competitive in advanced composites. Japan has a well-focused long-term advanced composite research program, and is gaining leadership in some areas.[22]

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Costs are significant in securing and processing raw materials. (Traditional aluminum costs $1 a pound, fiberglass $5/lb, and graphite composites cost $50-$60/lb). Conventional materials used in aerospace products and systems remain more cost-effective. The manufacturing process is complicated and still evolving. Certain areas need further study, e.g., the effects of oxidation on high temperature composite materials and the development of repair and replacement techniques applicable to composite materials. Furthermore, there is a shortage of skilled engineers trained in advanced composites.[23]

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Advanced material production requires low-cost, innovative manufacturing methods; advanced automated design techniques; and unified technical data bases.

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[22] Japan Technology Evaluation Center, *JTEC Panel Report on Advanced Composites in Japan*, March 1991.

[23] Aerospace Industries Association, *The Leading Edge: Key Technologies for the 1990s* (Series Reprinted from the *AIA Newsletter* Vol. 1 No. 1 through Vol. 2 No. 7), (AIA: Washington, DC)

CRITICAL TECHNOLOGY: Advanced Sensors

DESCRIPTION: Sensors are extensions of man's limited senses of sight and hearing and also perceptions of forces or motions such as acceleration, pressure, and vibration. Active sensors, such as radar, are most common. Passive sensors have become important for stealth technology. Advanced sensors go beyond current state-of-the-art sensors.

WHY IS IT A CRITICAL TECHNOLOGY: Improvements in both individual sensor systems and in combining information from several systems can greatly enhance performance to match ever-increasing requirements and challenges. Applications will be for commercial and military aircraft and helicopters, missiles, space vehicles, and ships and ground vehicles. Benefits would include much improved detection and recognition capability; computer-integrated sensor systems; capability for autonomous detection-reaction operation; greatly reduced life-cycle costs; and stealth and counter/stealth technology and systems. Overall, the payoff is better product performance at a lower price. U.S. space and civil aircraft could lose future commercial sales, if advanced sensor capabilities are not incorporated into next-generation products.

U.S. POSITION RELATIVE TO RoW: The United States currently leads the world in sensor technology, but this lead is diminishing. For example, the Europeans have the technological edge in sensor technology involving measurement of vibration, noise, and displacement. The French and British have made advances in infrared and radar sensor technologies. The Japanese lead in solid-state video imaging technologies.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: The United States holds the lead amongst NATO countries in sensor technology. The Soviets and several Central European countries are known to have made significant advances in sensor technology. Cost is the overriding inhibitor to sensor technology development: Raw materials and current manufacturing methods are expensive. A small customer base does not encourage supplier investment; currently only the government needs or can afford sophisticated sensor systems.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Some sensors incorporate semiconductor materials. Dependence on foreign semiconductors could have severe ramifications on the domestic ability to develop and produce sensor devices. More generally, sensor technology development also requires expert material and device processing, CAD tools, and automated manufacturing.

CRITICAL TECHNOLOGY: Aerodynamics

DESCRIPTION: Aerodynamics involves the complex physical laws, theories, computational analyses and testing methods that underlie the development, design and operational performance of aircraft. Areas of interest include turbulence formation prediction and its control; efficient, more representative CFD algorithms; grid codes for analyzing and optimizing aircraft and engine concepts; laminar flow concepts for enhancing airfoil efficiency; aerodynamic noise and sonic boom reduction; vortex instability and alleviation schemes; high Reynolds number effects; and advanced test and validation techniques.

WHY IS IT A CRITICAL TECHNOLOGY: Aerodynamics represents a potential for major improvement in subsonic aircraft efficiency and is an enabling technology for a viable high speed commercial transport. Advances in aerodynamic technologies lead not only to improved aeronautical products but can lead to significant reductions in product development cost and time. More accurate prediction of aerodynamic performance can greatly reduce the potential for costly and time consuming hardware modifications to correct design flaws.

U.S. POSITION RELATIVE TO RoW: The United States currently lags the Europeans in aerodynamic technologies, but still leads the Japanese. If current trends continue, it is anticipated that Europe will be on par with the United States by 2000. European high Reynolds number wind tunnel test facilities are more advanced than those in the United States.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: There has been an absence of a sustained, comprehensive national plan for aerodynamics research. Existing aerodynamic test facilities have been allowed to deteriorate and become obsolete. New facilities on par with those already existing in Europe are not being developed. Government research agencies, such as NASA, are not devoting enough resources to hardware validation of research results.

TECHNOLOGICAL INTERDEPENDENCIES – RELATED TECHNICAL ISSUES: Advanced CFD codes for aerodynamic optimization require improvements in computational sciences and hardware capability. Laminar flow control on wings and tail surfaces require advanced manufacturing techniques. Lightweight, complex shaped composites for primary structure require advances in manufacturing technology. Advanced aerodynamic configurations require flight control/avionics systems that serve to provide acceptable stability and control characteristics.

CRITICAL TECHNOLOGY: Airbreathing Propulsion Systems

DESCRIPTION: Airbreathing propulsion systems describe the type of engine technology used in aircraft and missiles, as well as in possible future applications to the space plane (NASP) and high-speed commercial transport (HSCT).

WHY IS IT A CRITICAL TECHNOLOGY: New propulsion technology developments in airbreathing engines will provide major gains in propulsion system capability for a wide range of potential applications. Within 20 years, advancements in propulsion technology could result in the design of subsonic transports requiring 30 percent less fuel; fighter aircraft with greater agility and survivability; sustained Mach 3+ flight speed capability and/or V/STOL capability; and rotorcraft with 100 percent greater range and payload. Generally, the payoffs include improved affordability, enhanced operability, increased thrust/weight, increased maneuverability and expanded payload/range without compromise to reliability/supportability.

U.S. POSITION RELATIVE TO RoW: The United States currently leads the world in airbreathing propulsion technologies.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Specifically, there has been an absence of sustained national plans for supersonic commercial aircraft propulsion development which will require substantial research and development to achieve an economically viable and environmentally acceptable system. More generally, and related to the above, there have been insufficient resources applied to the development and production of highly advanced materials which are critical to advancing propulsion technology.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Airbreathing propulsion technology is linked to development in such areas as turbomachinery; combustors/augmentors; inlets and exhaust systems; controls, accessories and mechanical systems; advanced automated methods; and especially advanced high temperature and lightweight materials.

CRITICAL TECHNOLOGY: Artificial Intelligence

DESCRIPTION: AI is an evolving set of software concepts and technologies directed at practical imitation of perception and reasoning. The process of integration, or intelligent systems engineering, is key to the use of AI in practical systems to provide real solutions to challenging mission needs.[24] AI covers the range of intelligent behavior necessary to achieve an action, including interpreting, assessing, planning, and acting.

WHY IS IT A CRITICAL TECHNOLOGY: Application of artificial intelligence may result in revolutionary productivity improvements for man/machine systems. Payoffs include viable access to the large amount of data increasingly available from space and other systems; national knowledge base assets (e.g., design and engineering, crisis response plans, etc.); autonomous systems for inaccessible environments, long duration missions, and minimum maintenance environments (e.g., Space Station Freedom); collaborative work environments for large software/hardware design, development, and maintenance; and reduced operator load in dealing with complex systems.

Artificial intelligence is already being applied in areas such as fault diagnosis, machine maintenance, satellite telemetry monitoring, robotic systems, and planning and scheduling.

U.S. POSITION RELATIVE TO RoW: The United States is currently on par with the Japanese in AI hardware, but lags behind the Europeans. The United States still leads both Japan and Europe in AI software. This situtation is not expected to change significantly over the next few years.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Research in AI has been funded primarily by DARPA, with relatively small additional contributions from industry and NASA. The level of funding from all of these sources in the United States is declining dramatically in comparison with the investment being made in Japan and Europe.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: AI is primarily a software technology, and thus both contributes to and places requirements on software development technology. In addition, AI increasingly requires large scale parallel computation; software development environments for large scale parallel hardware are critical to long-term progress.

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[24] AIA, *The Leading Edge*, p. 20.

CRITICAL TECHNOLOGY: Computational Science

DESCRIPTION: Computational science is the linking of software and hardware capability for human use. Improvements in computational science yield multifold increases in both speed and scope of computation.

WHY IS IT A CRITICAL TECHNOLOGY: Advances in computational science will mean significant increases in computational scope and capacity. The benefits will permeate all aspects of the aerospace industry including technologies development, product design, and systems maintenance.

U.S. POSITION RELATIVE TO RoW: The U.S. position is difficult to assess, much less predict. While the U.S. is the current leader in computational science, the Japanese and Europeans are gaining on U.S. capabilities.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Current U.S. supercomputing is under severe threat from Japan.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Computer science is dependent upon software, manufacturing processes, and computer operation/programming skills.

CRITICAL TECHNOLOGY: Optical Information Processing

DESCRIPTION: Optical information processing is concerned with the storage and manipulation of data by optical devices, using light, as opposed to the charged electron flow used in conventional electronics. This technology includes signal, image, numerical data, and symbolic data processing.

WHY IS IT A CRITICAL TECHNOLOGY: Innovation in optical information processing could lead to a thousandfold improvement in information processing performance (real-time speed) and reliability. There would be an order-of-magnitude reduction in the number and size of component interconnections, and this would help reduce weight in aerospace systems. In addition, optical information processing could result in less maintenance and a longer life for inaccessible systems.

U.S. POSITION RELATIVE TO RoW: The U.S. lead in optical information processing is rapidly diminishing. By the year 2000, this lead could be gone. Japan, in particular, is making inroads into U.S. leadership in this area. The United States is behind in many optoelectronic component technologies.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Technical maturation is slow. Materials and process are still evolving and customers are slow to accept it. With the exception of fiber optics, optical information technology has yet to demonstrate clear advantages over electronics for any application. Technology transfer is slow both on the inter-industry level and from DOD to industry. High costs are incurred because of the use of expensive specialized material compounds and the construction of clean room facilities.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Optical information processing would require developing specialized material compounds with nonlinear optical properties; innovative, low-cost manufacturing methods; and new, innovative device/component designs.

CRITICAL TECHNOLOGY: Rocket Propulsion Systems

DESCRIPTION: Rocket Propulsion Systems refers to engine technologies employed for use with space launch vehicles, orbit transfer vehicles, ballistic and tactical missiles, space intercepts, and on-orbit planetary.

WHY IS IT A CRITICAL TECHNOLOGY: Rocket propulsion technology advances could include increased reliability and safety, order-of-magnitude reductions in cost-to-orbit, and reductions in engine costs with improved performance. The prospect of lower costs and heavier payloads will promote commercial involvement in the space effort.

U.S. POSITION RELATIVE TO RoW: The United States still leads the world in rocket propulsion technologies, but other countries, particularly the Europeans, are gaining rapidly on U.S. capabilities in this area.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: The belief that rocket propulsion is a mature technology has resulted in underfunding in this technology area. The foreign competition in rocket propulsion systems is growing. In addition to insufficient funding, inadequate test facilities, and a shortage of skilled engineers, the lack of sustained, specific, long-range U.S. space goals has inhibited the continued development of rocket engines.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Critical areas involved in rocket engine technological development include advanced automated operational check out, improved materials, and improved manufacturing methods.

CRITICAL TECHNOLOGY: Software Development

DESCRIPTION: "Software" has been defined as the algorithms (procedural or mathematical approaches to problem solving) and instructions which cause computers to process data correctly in support of operational mission needs.[25] As the complexity of weapon systems increases, the demands for sophisticated and complex software is experiencing exponential growth. Since software development costs increase rapidly with program size and complexity, system costs are rising rapidly.

WHY IS IT A CRITICAL TECHNOLOGY: Improvements in software development methodology could lead to an order-of-magnitude increase in software productivity with corresponding decreases in cost and error rates. Among other things, this could mean ultra-survivable military aircraft, long-life affordable space systems, fail-safe air-traffic-control, cost-effective air defense systems, and ultra-low cost brilliant weapons.

U.S. POSITION RELATIVE TO RoW: The United States is in the forefront of this technology because electronic computers were first developed here; there is a wider base of companies in this country than elsewhere; and our strong university system and an environment that supports entrepreneurs also benefit software. However, other countries are catching up to the United States in software technologies. The Europeans currently lead the United States in certain areas of software development, and the competition is expected to become more intense over the next years.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Development of advanced software technology is currently inhibited by the level of funding. A second fundamental problem is the lack of formal understanding and focus in research efforts. Current efforts are fragmented between government, industry, and academia, whereas a more interdisciplinary approach is needed. There is also considerable concern about the availability of trained personnel.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Software development is dependent upon software engineering, mathematics, and computer programming.

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[25] AIA, *The Leading Edge*, p. 12.

CRITICAL TECHNOLOGY: Superconductivity

DESCRIPTION: Superconductors are materials through which electric currents flow without resistance. Traditional metalic superconductors required cooling to near absolute zero to be superconducting, which limited their application. High-temperature superconductors, discovered in 1986, are ceramic-like materials that become superconducting at much higher temperatures. They require much less refrigeration and are promising for many more applications.

WHY IS IT A CRITICAL TECHNOLOGY: These ceramic-like materials should provide order of magnitude improvement over copper microstrip and antenna elements at the same temperature. While aerospace applications will probably precede other applications, these applications will include superconducting analog/digital convertors, infrared detectors, superconducting transistors, as well as high-performance superconducting motors and generators, energy storage systems, and structural isolation systems.

U.S. POSITION RELATIVE TO RoW: Leading edge R&D is taking place in laboratories in the United States, Japan and Europe. The real challenge, however, lies in practical, commercial application, which could pose problems to U.S. industry.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Aggressive research programs and commercialization efforts overseas, as well as strong manufacturing capacity by foreign competitors all present a challenge to U.S. semiconductor producers.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Progress in superconductivity innovations is closely related to other materials research.

CRITICAL TECHNOLOGY: Ultrareliable Electronics Systems

DESCRIPTION: Ultrareliable electronics systems (URES) refers to provably correct designs. URES involves the employment and blending of key technologies and methodologies to enhance the reliability of complex electronic systems.

WHY IS IT A CRITICAL TECHNOLOGY: Ultrareliable electronics enable improved performance, integrity, availability and affordability of platform and vehicle systems. It is primarily a focus on reliability with payoffs including fundamentally failure free lifetime systems and significantly reduced life cycle costs.

URES require development of such supporting technologies as packaging and manufacturing, and development of systems and architectures such as intelligent sensors and actuators, self-healing systems, distributed systems, high-speed, fault-tolerant fiber optic data bases. Verification methodologies such as designed-in testability are needed.

U.S. POSITION RELATIVE TO RoW: The erosion of the U.S. position in electronic components has already cut into U.S. leadership in this area. Continued erosion of basic supporting technologies will signify continuing decline of the U.S. position into the future.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: The erosion of the U.S. position in electronic components poses a threat to U.S. prominence in URES.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Related areas include methods for designing and testing error-free systems and environmental screening; hardware and software failure models and system reliability prediction methodology; and advanced CAD tools for simulation.

CRITICAL TECHNOLOGY: Very Large Scale Integrated Circuits

DESCRIPTION: VLSI refers to compact circuitry which combines an increasing number of basic circuit elements, such as transistors, in a circle integration circuit. This will provide computers with an even greater computational ability, while at the same time, make them smaller, more reliable and easier to maintain. VLSI stands to benefit from the expertise gained through electronics microminiaturization, the emergence of new materials such as gallium arsenide, and advances made in superconductivity.

WHY IS IT A CRITICAL TECHNOLOGY: In addition to providing computers with greater computational capacity and reliability, VLSI will give unprecedented performance in aerospace and many other fields, providing "brains" for aircraft, satellites and weapons. They will also play a pivotal role in the development of other newly emerging fields, such as artificial intelligence, and will be applied broadly throughout the civil economy.

U.S. POSITION RELATIVE TO RoW: The United States is currently behind, particularly the Japanese, in VSLI technology. If current trends continue, the United States will have largely lost its position in this industry by the year 2000.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Although the U.S. pioneered integrated circuits, foreign manufacturers now dominate production of many commercial semiconductor devices and have rapidly implemented new technology, including VLSI.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Major areas of emphasis include improved design simulation; submicron scale device fabrication; enhanced aerospace attributes such as ruggedness, testability, and radiation hardness; advanced semiconductor materials; and interconnecting and packaging.

III. THREATS TO U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES:

Foreign Competition -- Targeting and Subsidies: Foreign governments, particularly in Europe and Japan, but also in Indonesia and Brazil, have deliberately targeted aerospace as a critical industry. These foreign governments support their aerospace industries in the form of generous loan conditions and policies that mitigate risk. As a result, these foreign industries have been able to develop highly advanced aerospace technologies for commercial application with limited concern about cost.

R&D Funding: Because aerospace is technology-driven and on the forefront of (expensive) innovation, it requires large amounts of R&D investment. The U.S. government funded about 40 percent of aerospace R&D in 1988. DOD accounted for 77 percent of that sum, directed to military programs at the development stage. The FAA contributed another 14 percent in 1988, geared to air traffic control and air safety. NASA's work in high-risk civil aviation R&D programs (targeting basic and applied research activities) accounted for another 9 percent. U.S. manufacturers provided about 20 percent of aerospace R&D funding.

R&D investment and commitment is difficult to attain for a variety of reasons, among them the high cost of capital (on the private side) and various recent procurement revisions (on the military side). Limits on the aggregate amount of IR&D/B&P costs that DOD could negotiate with industry has led to lower IR&D spending in defense because of lower recovery costs.

Fiscal Policy Inconducive to Long-term Investment: Single-year procurements and single-year budgets thwart long-term planning for defense-related aerospace. Because the R&D tax credit is (1) not permanent, (2) only applied to an increase in expenditure above a company's historical outlays, and (3) only applied to incremental, early program costs, it fails to stimulate the aerospace industry's long-term investment in R&D.

The high cost of capital can be traced to high Federal budget deficits. High cost of capital acts as a strong disincentive to borrowing; investment in R&D suffers as a consequence.

Insufficient Intra-Industry Interaction: Like many other U.S. industries, aerospace suffers from the "Lone Ranger" syndrome. A microsystem management philosophy versus a systems approach has led to limited inter-industry communication. Antitrust legislation has contributed to this restrictive behavior.

Weak Links in the R&D Chain -- Validation: Because aerospace products are expensive, sophisticated, and face critical requirements in terms of performance and safety, they are necessarily subject to a lengthy and expensive process of validation. Unfortunately, validation is one of the weakest links in the U.S. aerospace industry's R&D chain. Not only is there a shortage of test-facilities for validation (NASA and military facilities are not used directly for commercial purposes), the process itself has become prohibitively expensive and time-consuming. The U.S. aerospace industry must work to expedite the validation process or risk losing the competitive edge to its international competitors who are becoming increasingly adept at transferring experimental prototypes to commercially feasible products.

Lack of Qualified Engineers/Technicians: The average age of aeronautical/astronautical engineers has risen more sharply than that for all engineers over the decade. Between 1976 and 1986, the proportion of aeronautical/astronautical engineers over age 50 rose from 26 percent to 49 percent; the proportion of all engineers in this age group increased from 24 to 34 percent.[26] The education pipeline is not providing sufficient numbers of highly trained scientists and technicians to fill future ranks, especially in advanced areas. There are fewer and fewer American students studying math and science, especially at the graduate level. Forty percent of science/engineering graduate students at American universities are foreigners.

Outdated Trade Policy: U.S. export controls for certain "critical" technologies have hindered U.S. aerospace exports. Some of these controls may need to be reviewed. Insufficient protection of intellectual property has also acted as a disincentive to aerospace firm investment in new technologies.

IV. OPPORTUNITIES

High Levels of R&D Spending: The industry has one of the highest levels of R&D spending of any U.S. industry, both in terms of government spending (mostly DOD, but also NASA and the FAA) and private industry spending (known as independent R&D). In 1987 company and government R&D funding combined amounted to 15 percent of net sales, compared with the all-industry average of 4.7 percent. Private industry spending was 3.7 percent of net sales, compared to a 3.3 percent average for all manufacturing.

Superior Systems-Integration Capability: The American aerospace industry is particularly adept in systems-integration and is, in fact, considered the world's leader in this critical area.

Long-term Thinking: While arguably not as forward-looking and as eager a risk-taker as it once was, the U.S. aerospace industry continues to draw on a tradition of greater patience than most other industries in the country.

Industry Restructuring Efforts/Awareness of Challenge: With the decline of several key U.S. manufacturing industries as poignant warnings to other industries, the U.S. aerospace sector has made a concerted effort on both the micro and the macro level to address the growing foreign challenge.

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[26] National Science Foundation, *Profiles -- Aeronautical/Astronautical Engineering: Human Resources and Funding*, Special Report, NSF 89-314 (Washington, DC: NSF, 1989), p. 15.

Public Support: For the same reasons that other countries view aerospace as a strategic and prestigious industry, the United States stands strongly behind it. NASA and DOD programs support aerospace both directly and indirectly, reflecting a high national political priority.

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

Council Associate Andreé Dumermuth prepared this report. The Council would like to thank the Aerospace Industries Association and the Boeing Company for their work in the preparation of this profile.

The Council would like to thank Pfizer Inc. and NMTBA/The Association for Manufacturing Technology for their assistance in publishing the profiles.

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*Dr. Spencer served on the Committee in his role as Vice President, Science and Technology, Xerox Corporation, prior to his appointment to Sematech.

ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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A COMPETITIVE PROFILE OF THE

CHEMICAL AND ALLIED PRODUCTS INDUSTRY

Research Paper for

GAINING NEW GROUND:

TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future.*

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling.

SECTORAL PROFILE: CHEMICAL AND ALLIED PRODUCTS

SUMMARY

Key Points

- The industry is **large and diverse**. It produces thousands of products, from bulk chemicals to finished products.

- The industry is in part **a basic industry** and in part **a high-technology industry**. In the basic part, competitiveness is based on providing basic commodities at the lowest price. In the more high-technology parts of the industry, competitiveness is based on propriety product and process technology.

- The industry has maintained a **trade surplus**. This surplus declined in the early 1980s, but recovered after the industry underwent a difficult (and still continuing) restructuring.

- It is highly **global**, which the industry sees as a source of strength. Foreign direct investment in the U.S. chemical industry is equivalent to about 13 percent of the industry's assets. U.S. investment in foreign chemical industries is comparable.

- It is **closely linked to the rest of U.S. manufacturing**. About half of the industry's output is used by other manufacturing industries. Chemical industry products aid the competitiveness of other industries, and the strength of those industries, in turn determines the market for the chemical industry.

- It is **capital intensive**. In 1985, capital per employee was $92,300, compared to an industry average of $42,900.[1]

- It is **R&D intensive**. 1988 R&D expenditures were equal to 4.6 percent of sales,[2] compared to about 2.8 percent for manufacturing as a whole.

- It is **highly regulated**. Environmental, health, and safety laws control the environmental release, disposal, transportation, workplace exposure, and use of various chemical products.

- It **competes and cooperates with other industries**. The products of the chemical industry compete with metals, wood, and other materials. The chemical industry and other industries compete and collaborate to produce specialized materials, such as those for electronics and aerospace.

Critical Technologies

- Biotechnology

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[1] Bozdogan, Kirkor, "The Transformation of the U.S. Chemical Industry," The Working Papers of the MIT Commission on Industrial Productivity, Vol. 1, Cambridge, MA, The MIT Press. p. 8-10.

[2] Lenz, Allen J., The U.S. Chemical Industry 1988-1989, Washington, Chemical Manufacturers Association, May 1989. p. 18.

- Synthesis Capability
- Catalysis and Reaction Mechanism Understanding
- Electronic and Structural Ceramics
- Composites and Associated Fabrication Technologies
- Non-Linear Optical Materials
- Superconducting Materials and Fabrication Technology
- Specialty Polymers
- Supercomputers, Leading Edge Software, and Product and Process Modeling
- Artificial Intelligence and Neural Network Technology
- State of the Art Analytic Instruments
- Advanced Sensors and Process Control
- Membranes
- Environmental Technologies
- Precision Coating
- Precision Machinery

Threats to U.S. Leadership in Critical Technologies

- High capital costs relative to competitors in other countries.
- An unpredictable product liability environment that acts as a disincentive to innovation.
- Uncertain of end-user demand for advanced materials.
- Exports controls and other barriers to commercializing defense technologies.
- Environmental regulations designed with little consideration of competitiveness.
- Inadequate worldwide protection of intellectual property.
- Weak precollege science education

Factors Supporting U.S. Leadership in Critical Technologies

- A corporate tradition of technology development and management.
- Strong industrial R&D spending.

- A healthy U.S. technological base and university education system, and effective university-industry linkages.
- Defense research, development, and procurement of advanced materials.
- Environmental regulations that stimulate technological innovation.

I. INDUSTRY CHARACTERISTICS

Industry Size and Segments

The chemical industry can be divided in several ways. One ways is the **standard industrial classification** (SIC) system, based on product classes, used by the Department of Commerce (see table below).

			1987	
SIC Code	Industry	Employment (thousands)	Shipments (bil. $)	Value Added (bil. $)
SIC 28	Chemical and Allied Products Allied Products			
SIC 281	Industrial Inorganic Chemicals	93.9	33.4	9.3
SIC 282	Plastic Materials, Synthetic Rubber, Manmade Fibers	123	40.9	17.8
SIC 283	Drugs	170	39.1	28.0
SIC 284	Soaps, Cleaners, and Toilet Goods	119	34.4	21.4
SIC 285	Paints and Allied Prod.	54.7	12.6	6.2
SIC 286	Industrial Organic Chemicals	125	51.4	21.5
SIC 287	Agricultural Chemicals	39.7	14.2	6.3
SIC 289	Misc. Chemical Products	85.3	16.8	8.2

A second way of dividing the industry is according to **technology intensity**. Some segments of the industry, in particular SIC 281 and 286, produce mainly standard commodities, and competition is based on providing the commodity at the lowest price. Process technology and raw material costs are keys to competitiveness. Other segments of the industry, such as pharmaceuticals and pesticides, are mainly high value-added, R&D-intensive products, and competitiveness is based on having a superior proprietary product. In between, there are an enormous number of products that are intermediate in both technology and production volume, such as polymers, fiber, paints, adhesives, etc. These contain a mix of commodity and specialized products. For example, some polymers are considered commodities while others are R&D intensive.

A third way of dividing the industry is according to the **degree of regulation**. Although all of the chemical industry is regulated under safety and environmental laws, some segments, such as pharmaceuticals and pesticides, are more highly regulated. In these segments, regulatory agencies must approve new products before they can be used, and thus have a major influence on the technology development process.

Size Distribution of Companies

The chemical industry includes many large, highly diversified firms and many small, highly specialized firms. Concentration varies somewhat according to the segment of the industry. Market share of the largest 8 firms in four digit SIC segments varies from 100% (carbon black) to 25% (chemical preparations, not elsewhere classified); most range from 30% to 70%.

One chemical industry analyst divides the industry into three principal groups of companies:[3]

1. The **flagship high-technology companies**. Although some still produce commodity chemicals, their emphasis is on such areas as advanced materials, pesticides, biotechnology, electronic materials, drugs and medical devices, and newer specialty chemicals.

2. The **commodity chemicals and plastics group**. Many of these were spun off by the flagship companies or by firms leaving the chemical business during the restructuring of the early 1980s. They include some large firms and several medium sized companies.

3. **The high-value, small-volume group**. These include the small and medium sized companies, which, in addition to the flagship producers, make specialty chemicals, fine chemicals, and pharmaceutical.

Some firms are vertically integrated. For example, Dupont produces raw materials (through its Conoco subsidiary), and produces finished consumers goods. Most are less integrated, and purchase feed stocks from petroleum or mining companies, or purchase commodity chemicals from other chemical companies to produce specialty chemicals.

Key Relationships with Other Industries

The chemical industry is closely connected with virtually every other manufacturing industry.

Upstream Relations:

- The petroleum and mining industries provide basic feedstocks and energy for the chemical industry.

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[3] Kline, Charles H., "Sorting Out New Roles," Chemicalweek, August 2, 1989. p. 78-82.

- Universities provide skilled personnel and knowledge.

- Equipment and instrument manufacturers provide process and scientific equipment and instruments (including computers and software).

Downstream Relations

- The rubber and plastic products industry uses plastic and rubber materials produced in the chemical industry.

- Agriculture uses the fertilizers, pesticides, and veterinary drugs produced by the chemical industry.

- The textile industry uses man-made fibers.

- The automobile industry uses paints, adhesives, plastics, rubber, and fibers, and is beginning to use ceramics and advanced composites.

- The building industry uses fibers, paints, ceramics and composites.

- The electronics industry uses specialized materials and chemicals in many applications, from semiconductors to plastics for product cases.

- The aerospace industry uses plastics, rubber, and fibers, and is increasingly using advanced composites and ceramics.

- The food processing industry uses food additives produced by the chemical industry and shares some of the same processing technologies.

- The paper industry and the glass industry use many chemicals and share some processing technologies.

Advanced materials are at the interface of several industries, including traditional material industries such as the chemical, metals, and building material industries, and industries that use specialized materials, such as the aerospace, automobile, electronic, and medical equipment industries. Innovations in materials can come from any of these industries.

Relationship to National Defense

At a general level, the chemical industry, with its ability to transform a vast variety of raw materials into a vast variety of products, enhances U.S. security by lessening U.S. dependence on particular raw materials from foreign sources. At a more specific level, the products produced by the chemical industry have many defense applications. Some of these are as follows:

- Advanced structural materials for aerospace, weaponry, and armor.

- Propellants for missiles and rockets.

- Explosives and ammunition.
- Electronic materials for semiconductors and electronics.
- Special materials for nuclear weapons.
- Defoliants.
- Pharmaceuticals.
- Textiles for tents, uniforms
- Chemicals for chemical and biological warfare.

In most areas, the military market is much smaller than the civilian market. In a few specialized areas, such as explosives and composites for aircraft, the defense market is much larger than the civilian market and has a strong influence on the industry.

The Department of Defense (DOD) and the Department of Energy (DOE) funded $130 million and $149 million in chemical research in 1989, accounting for 18 percent and 21 percent respectively of the total U.S. government funding of chemical research.[4] DOD and DOE also dominate government funding of chemical engineering research and metallurgy and materials research.[5] These figures do not include research conducted in classified programs.

Not all military influence is positive for the chemical industry. Some advanced materials are subject to export control regulations, which requires companies to receive export licenses. Delays in receiving these licenses can result in a loss of sales.[6] The United States also requires companies in other countries to obtain U.S. approval to re-export products with U.S. components to third countries. This provides a disincentive for other countries to buy U.S. products.[7] Another negative influence comes from chemical warfare, which is widely perceived to worsen the public image of chemicals.

Regulation of the Chemical Industry

The chemical industry is subject to regulation under many statutes. These affect the industry's products, processes, and production costs. The major environmental, health and safety laws that affect the industry are as follows:

The **Toxic Substances Control Act (TSCA)** gives EPA the authority to regulate toxic substances. Among other features, it requires chemical companies to submit premanufacture notices for each new chemical that include information on health and environmental effects.

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[4] Rawls, Rebecca L., "Facts and Figures for Chemical R&D," Chemical and Engineering News, August 21, 1989. p. 28-61.

[5] Ibid.

[6] U.S. Congress, Office of Technology Assessment, Advanced Materials By Design, Washington, U.S. Govt. Print. Off, June 1988. p. 272-287.

[7] Ibid.

The **Clean Air Act** provides the authority under which the EPA regulates air pollutants from chemical plants. It also influences the markets for products the industry produces, such as gasoline additives.

Superfund establishes a fund for cleaning up waste sites by means of a tax on the oil, chemical, and other industries. The **Superfund Amendments and Reauthorization Act (SARA)** of 1986 also establishes "right to know" standards that requires chemical plants to provide information to the public about stored toxic chemicals and annual releases into the environment.

The **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)** governs EPA regulation of the safety of pesticides.

The **Food, Drug, and Cosmetics Act** provides FDA the authority to regulate the safety of foods, drugs, and cosmetics.

The **Resource Recovery and Conservation Act** provides EPA with the authority to regulate the management of solid and hazardous wastes.

Other acts that affect the chemical industry include: (1) the **Occupational Safety and Health Act**, which governs workplace safety and health, including permissible exposures to chemicals in the workplace; (2) the **Clean Water Act**, which provides EPA the authority to regulate effluents into waters; (3) the **Safe Drinking Water Act**, which regulates groundwater pollution and influences fertilizer use; (4) the **Hazardous Materials Transportation Act**, which provides the Department of Transportation with the authority to regulate the safety of shipments of hazardous materials; and (5) the **Chemical Diversion and Trafficking Act**, which is designed to control the diversion of chemicals to illegal drug producers.

In addition these Federal statutes, there are also international agreements and state laws. For example, the **Protocol to Limit Emissions of Chlorofluorocarbons**, signed in Montreal, Canada in 1987 is intended to limit chlorofluorocarbon production. Notable among state laws is **Proposition 65** in California, which provides for public warnings about exposure to hazardous chemicals and prohibits the discharge of significant amounts of hazardous chemicals into actual or potential sources of drinking water.[8] Other states also have laws that affect the chemical industry.

Competitive Position of the U.S. Chemical Industry

The U.S. chemical industry has been in a dominant position since World War II and has had a trade surplus. The industry experienced a major downturn from 1979 to 1985 and the trade balance sharply declined. The industry has been going through a painful period of restructuring. It divested or downsized many commodity chemical operations. It diversified into specialty chemicals and higher value products, such as pharmaceuticals, advanced materials, and medical instruments, that allowed a greater degree of product differentiation. U.S. chemical companies withdrew from Europe to stop financial losses. Poorly performing companies were taken over by corporate raiders. U.S. companies underwent internal reforms and[9]

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[8] Mackerron, Conrad B., "Industry Learning to Live With Proposition 65," Chemicalweek, July 12, 1989, p. 18-20.

- developed a strategic corporate vision;
- emphasized R&D and technology development;
- adopted a market-driven orientation;
- emphasized productivity, quality, and human resource management;
- created new organizational systems for greater efficiency, innovation, better communication, and quicker response to the marketplace.

This restructuring has been generally successful and is continuing.

Trade

Chemical Industry Trade
(billions of current dollars)

Year	Exports	Imports	Balance
1980	20.7	8.6	12.1
1982	19.9	9.5	10.4
1984	22.3	13.7	8.6
1986	22.8	15.0	7.8
1988	32.4	20.8	11.6

Source: Lenz, Allen J., The U.S. Chemical Industry 1988-1989, Washington, Chemical Manufacturers Association, May 1989.

Chemical imports are equivalent to about 7-10% of domestic shipments; exports are equivalent to 12-13% of shipments. A disproportionate amount of this trade is in commodity chemicals -- while industrial organic and inorganic chemicals represent only 27.5 percent of the total chemical shipments, they represent 43 percent of the U.S. exports and about 57 percent of the U.S. imports.[10]

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[9] Bozdogan, Kirkor, "The Transformation of the U.S. Chemical Industry," The Working Paper of the MIT Commission on Industrial Productivity, Vol. 1, Cambridge, MA, The MIT Press. p. 44.

Foreign Investment

The chemical industry is one of the most global industries. Foreign investment in the U.S. chemical industry is rapidly increasing, and is currently equal to 13 percent of the assets of the industry.[11] 32.5 percent of all chemical assets in the United States are held by firms that are substantially (more than ten percent) foreign owned.[12] This is a higher percentage than for other major industries.

Foreign Investment in the Chemical Industry
(billions of current dollars)

Year	U.S. Direct Investment Abroad in Chemical Industry	Foreign Direct Investment In U.S. Chemical Industry
1984	19.2	16.6
1985	20.2	18.8
1986	22.7	23.0
1987	27.0	29.9
1988	30.5	34.1

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Current Business, August 1989.

Of the $34.1 billion in foreign investment in the U.S. chemical industry, 31% was U.K. owned, 22% German owned, and 3% Japanese owned. The Japanese investment is increasing, with Japanese companies acquiring chemical plants to support other Japanese industry, such as automobile manufacturers, that have located in the United States.[13]

U.S. income from foreign investment in the chemical industry still exceeds foreign income from investments in the U.S. chemical industry, which suggests that the true value of the U.S. investment abroad probably still exceeds the value of foreign investment in the United States.

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[10] Lenz, Allen J., The U.S. Chemical Industry 1988-1989, Washington, Chemical Manufacturers Association, May 1989. p. 9-10.

[11] Total assets in 1988 were estimated at $255.6 billion; foreign investment was $34.1 billion.

[12] Lenz, Allen J., The U.S. Chemical Industry 1988-1989, Washington, Chemical Manufacturers Association, May 1989. p. 9-10.

[13] Hunter, David, Japan on Rise in the U.S. CPI, Chemicalweek, August 9, 1989. p. 16-18.

Investments are recorded at the book value of the original investment and, because U.S. investments abroad tend to be older than foreign investments in the U.S., they are more likely to be undervalued.

Income and Payments from U.S. Chemical Industry
International Investment
(billions of current dollars)

Year	Income From U.S. Direct Investment Abroad	Payments from Foreign Direct Investment in U.S.
1982	1.1	0.3
1984	1.2	0.8
1986	4.2	0.5
1988	6.0	3.0

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Survey of Current Business, August 1989.

Growth and Profits

The industry is generally healthy. It has been consistently profitable, and since the restructuring in the early 1980s (see page 16), profits have grown.[14] It has also been growing steadily; production has increased in all but three years since 1970, and chemical industry production has grown faster than industrial production as a whole since 1970.[15]

Capital Investment

Capital expenditures have been relatively flat. They grew from $8.4 billion in 1978 to 18.5 billion in 1988,[16] which, after adjusting for inflation, represents about 25 percent growth over the decade.

Trends in Patents

The U.S. share of U.S. chemical patents is declining. The decline is slightly slower than the decline in U.S. share of all U.S. patents.

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[14] Economic Report of the President, Washington, U.S. Govt. Print. Off., February 1990. p. 397.

[15] Economic Report of the President, Washington, U.S. Govt. Print. Off., February 1990. p. 350.

[16] Lenz, Allen J., The Chemical Industry, 1988-1989, Washington, Chemical Manufacturers Association, May 1989, p. 19.

Share of U.S. chemical patents

	1979	1988
United States	59%	52%
Japan	11	20
West Germany	11	11
United Kingdom	4	4

Source: Chemical and Engineering News, August 21, 1989 p. 34.

Trends in the Science Base

U.S. articles account for 22 percent of all world scientific and technical articles in chemistry, a percentage that has changed little in the past fifteen years.[17] This percentage is lower than for most other areas of science. The U.S. share of chemical engineering articles was 39.3 percent. U.S. papers in chemistry tend to be more highly cited than papers from other countries, indicating that they tend to be more significant.[18]

Outlook

Because 50% of U.S. chemical industry output goes to other manufacturing industries, the outlook for the U.S. chemical industry depends not only on the competitiveness of the U.S. chemical industry, but also on the competitiveness of U.S. manufacturing industry and the health of the world economy in general.

There are several ongoing shifts in the products and markets in the industry:

- **A shift toward the high value-added products.** Chemical companies in the United States, Europe, and Japan are increasingly becoming R&D-based companies, and are moving into specialty chemicals, advanced materials, and biotechnology.
- **Increasing competition at both the low and high value-added ends of the business.** Competition at the low end comes from oil companies and chemical companies in developing countries. At the high end, chemical companies in the developed countries are all shifting to high-value added products, resulting in intense competition.

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[17] The U.S. share was 23 percent in 1973, fell to 20 percent by 1981, and rose to 22 percent in 1986. National Science Board, Science and Engineering Indicators - 1989, Washington, U.S. Govt. Print. Off., 1989, p. 327-330.

[18] National Science Board, Science and Engineering Indicators - 1989, Washington, U.S. Govt. Print. Off., 1989, p. 343.

- **Increasing competition and cooperation with non-chemical companies.** Chemical companies are in competition with metals and other materials companies in some parts of the market, and cooperate and compete with electronics and aerospace companies in other parts of the market.

- **Increasing environmental concerns**, leading to more environmentally benign products and processes. Concerns about global warming, waste disposal, and hazardous chemicals in the air and water are leading to the increased use of recycling, less polluting processes, and environmentally benign products, and the decreased use of fertilizers and pesticides.[19]

- **Increasing globalization.** Europe 1992 is accelerating this process by encouraging U.S. and Japanese firms to be invested in Europe. Foreign investment in the U.S. chemical industry is increasing.

II. CRITICAL TECHNOLOGIES [20]

The chemical industry was essentially born in research laboratories, and the development of technology has continually shaped the industry. Much of the technology development in the industry can be characterized as research driven but incremental -- virtually all advances in chemistry have come out of laboratory research but much technical progress is in small improvements over time rather than through major breakthroughs.

As part of its restructuring, the industry has been increasing R&D spending. Total chemical industry R&D was estimated to be $11 billion in 1988 (almost $5 billion of this was for drug R&D).[21] For 12 large U.S. chemical companies included in Chemical and Engineering News survey, R&D as a percentage of sales increased from 3 percent in 1980 to almost 6 percent in 1989.[22] The industry average is somewhat lower, about 4.6 percent of sales.[23] A similar trend is taking place in other countries. The Japanese chemical industry increased its R&D

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[19] Lepkowski, Wil, "Debate Builds Over Alternative Agriculture," Chemical and Engineering News, November 27, 1989, p. 38-39.

[20] National Research Council, Material Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials, Washington, National Academy Press, 1989.

[21] Rawls, Rebecca L., "Facts and Figures for Chemical R&D," Chemical and Engineering New, August 21, 1989, p. 47.

[22] Reisch, Marc S. "Chemical Industry R&D Spending Continues to Climb," Chemical and Engineering News, January 15, 1990, p. 11.

[23] Data from Lens, Allen J., The Chemical Industry, 1988-1989, Washington, Chemical Manufacturers Association, May 1989, p. 3,18.

spending from 2.8 percent of sales in 1982 to 4.0 percent of sales in 1986.[24]

Technical Alliances

The U.S. chemical industry is also increasing its number of technical alliances, both national and international, to acquire and exploit technology.

The roles of technology and the critical technologies differ in various parts of the industry. In the commodity chemicals, the critical technologies are process technologies that provide a cost or quality advantage. In other sectors of the industry, both product and process technologies are important.

Technologies in the chemical industry can be divided into four groups: 1) products; 2) processes; 3) equipment; and 4) instruments.[25] Innovations in products and process largely come from inside the industry, and are often closely linked -- new products often require new processes. Innovation in the equipment and instruments generally come from outside of the industry.

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[24] Japanese Management and Coordination Agency, Report on the Survey of Research and Development, 1987. p. 82.

Chakrabarti, Alok K., "Innovation and Productivity: An Analysis of the Chemical, Textiles and Machine Tool Industries in the U.S., Research Policy, (in press) 1989.

CRITICAL TECHNOLOGY: Catalysis

DESCRIPTION: Catalysts are substances used to promote chemical reactions.

WHY IS IT A CRITICAL TECHNOLOGY? There is a tremendous potential for improved catalysts, which can improve the efficiency of chemical processes and make it possible to make new products or the same products from new inputs. Catalysts are critical in waste reduction and recycling.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000			X

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Possible future shortage of researchers. Possible failure to adequately fund basic and precompetitive research. High cost of capital makes it difficult to make investment in new chemical processes and takes away incentives to do research.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Development of new catalysts is related to advancements in synthetic organic chemistry, surface chemistry, scientific instruments, and computers and software.

POLICY ISSUES: Basic research funding, science education, cost of capital. NSF's Kinetics and Catalysis Program.

CRITICAL TECHNOLOGY: **Leading Edge Synthesis Capability**

DESCRIPTION: Synthesis capability is the ability to make new chemical substances from simpler compounds or elements.[26]

WHY IS IT A CRITICAL TECHNOLOGY? Synthesis capability makes possible the creation of new substances. These new materials enable the creation of new products and the improvement of existing products.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Possible shortages of research chemists. Future insufficient funding of long term research, both by government and by industry.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Leading edge synthesis capability depends on access to state of the art scientific and analytical instruments and super-computers and software.

POLICY ISSUES: Basic research funding; science education.

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[26] National Research Council, Material Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials, Washington, National Academy Press, 1989. p. 212.

CRITICAL TECHNOLOGY: **Reaction Mechanism Understanding**

DESCRIPTION: Understanding the details of chemical reactions, including the steps that take place, the intermediate products, and the rates of the steps.

WHY IS IT A CRITICAL TECHNOLOGY? Basic knowledge that enables the creation of new products, better catalysts, and better processes.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: A lack of basic research funding, or a lack of research chemist would threat U.S. prominence.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: An understanding of reaction mechanism is closely related to catalysis, synthesis capability, and process design.

POLICY ISSUES: Basic research funding; science education.

CRITICAL TECHNOLOGY: **Biotechnology**

DESCRIPTION: Using modified living organisms or protein products derived from them for commercial purposes. Includes recombinant technology, hybridomas, and bioprocessing techniques.[27]

WHY IS IT A CRITICAL TECHNOLOGY? Emerging and enabling technology with applications in specialty chemicals, drugs, waste treatment, environmental cleanup and remediation, agricultural chemicals, and commodity chemicals. Agricultural applications include improved pesticides, animal health-care products, and genetically engineered crops. Waste treatment applications include using microorganisms to degrade a wide variety of industrial wastes. Specialty chemicals that can be produced through biotechnology include amino acids, vitamins, and enzymes. Some commodity chemicals may eventually be made from biomass feedstocks using microorganisms for processing. Bioelectronics -- the development of biologically produced materials to make sensors or semiconductor chips -- are a more distant application.[28] Critical elements of bioprocessing engineering include bioreactor design, process monitoring and control methods, and product purification.[29]

U.S. POSITION RELATIVE TO RoW:

R = Research
P = Products

	Lag	Par	Lead
1990		P	R
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Possible future shortage of researchers. Possible failure to adequately fund basic and precompetitive research. High cost of capital makes it difficult to make investment in new chemical processes and takes away incentives to do research. Possible tightening of regulatory environment for biotechnology. Focused foreign efforts on technologies of commercial importance.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on basic research in molecular biology, scientific instruments and computers, process monitoring and control, separation and purification technologies.

POLICY ISSUES: Basic research funding, regulatory environment, science education, university/industry relations, cost of capital.

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[27] "Old" biotechnology techniques include the use of microorganisms for brewing, or selective breeding in agriculture or crop genetics. Definitions come from U.S. Office of Technology Assessment, **New Developments in Biotechnology: U.S. Investment in Biotechnology**, Washington, U.S. Govt. Print. Off. July 1988. p. 3.

[28] U.S. Congress, Office of Technology Assessment, Commercial Biotechnology: An International Analysis, Washington, U.S. Govt. Print. Off., 1984. p. 253-257.

[29] National Research Council, Committee on Chemical Engineering Frontiers, Frontiers in Chemical Engineering: Research Needs and Opportunities, Washington, National Academy Press, 1988. p. 28-31.

CRITICAL TECHNOLOGY: **Electronic and Structural Ceramics**[30] [31]

DESCRIPTION: Ceramics -- non metallic and non-organic solids -- used for their electronic or structural properties. They are light, hard, and chemically inert, have high compressive strengths, survive high temperatures, and are good electrical and thermal insulators. Weaknesses to overcome are that they tend to fracture easily and are difficult to process.

WHY IS IT A CRITICAL TECHNOLOGY? They are "enabling" technologies that make possible other technologies, such as high temperature engines. High performance ceramics have many potential applications in electronics (for capacitors and integrated circuit packaging), biomedical devices, engines, and high-temperature superconductors. Lower cost ceramics have applications as building materials. The world market for high performance ceramics is estimated to grow from about $4.5 billion in 1988 to $11.2 billion in the year 2000.[32]

U.S. POSITION RELATIVE TO RoW:

		Lag	Par	Lead
Electronic Ceramics=E	1990	E	S	
Structural Ceramics = S	2000	E	S	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Underinvestment in industrial research in the U.S. Uncertainty about market demand. Weaknesses in U.S. semiconductor industry demand for electronic materials. Foreign targeting.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on advanced analytical instruments. Important technology for jet and rocket engines and for reactors. DOD and DOE research support has been important.

POLICY ISSUES: Export control; R&D funding; Federal procurement; Technology transfer from DOD/DOE labs; Cost of Capital.

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[30] National Research Council, Material Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials, Washington, National Academy Press, 1989.

[31] U.S. Office of Technology Assessment, Advanced Materials By Design: New Structural Materials Technologies, Washington, U.S. Government Printing Office, 1988.

[32] Strategic Analysis Inc., "Ceramics and Superconductors," Chemicalweek, September 27, 1989, p. 56-62.

CRITICAL TECHNOLOGY: Composites and Fabrication Technology

DESCRIPTION: Inorganic (ceramic and metal matrix) and organic (polymer matrix) composites and related fabrication technologies. Composites are combinations of two or more materials usually designed to give properties that improve on those of each material separately. They usually consist of reinforcing materials imbedded in a matrix of either polymers (polymer matrix composites) or metal (metal matrix composites). Composites are currently being used primarily in aerospace and sporting goods, but their uses are expected to expand greatly as prices come down and the technologies improve. They are also being used in armor and medical implants. Demand would expand if composites become cheap enough to be used in automobiles. The prices of polyacrylonitrile (PAN)-based carbon fiber has dropped from $100/lb to $20/lb, but the auto industry wants prices of around $3-5/lb.[33]

WHY IS IT A CRITICAL TECHNOLOGY? Composites can be lighter and stronger than the materials they replace, and thus can greatly improve the performance of many technologies, for example allowing more fuel efficient and higher performing airplanes and automobiles. High manufacturing costs are current barriers to more widespread applications. The advanced polymer composite market has been estimated to grow from $2.3 billion in 1988 to $6 billion in the year 2000.[34] The main obstacles are in processing and manufacturing, which currently is a labor intensive, many-step process.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

Source:JTEC

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: More systematic, long-range approach to composite technology development in Japan. If industries in other countries, such as the Japanese auto industry, use composites in mass volumes before U.S. industries use them, foreign composite producers could gain an advantage. Airframe and aerospace industry has driven technology -- weaknesses in the U.S. aerospace industry or in defense procurement could hurt U.S. prominence in the technology.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Aerospace, motor vehicles are large markets that can drive the technology. Solid state chemistry, interface and surface science, supercomputers and modeling, and processing technology are critical related sciences and technologies.

POLICY ISSUES: DOD R&D and procurement; Export control; Cost of capital.

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[33] Goldbaum, Ellen, "Composites: Geometric Growth Ahead", Chemicalweek, September 27, 1989. p. 41-52.

[34] Goldbaum, Ellen, "Composites: Geometric Growth Ahead", Chemicalweek, September 27, 1989. p. 41-52.

CRITICAL TECHNOLOGY: Specialty Polymers

DESCRIPTION: Polymers are giant organic molecules made up of chains of simpler molecules. Some polymers are produced in high volume and are considered commodities; others are specialized high technology products. Includes "smart" polymers (responsive to stimuli), and polymers that are strong, heat resistant, or have special electronic or biological characteristics.

WHY IS IT A CRITICAL TECHNOLOGY? They have a vast variety of uses, from armor to adhesives. Their advantages are high strength, flexibility, light weight, and favorable thermal, electrical, and optical properties for some applications. Increased understanding of polymer chemistry coupled with increased computer modeling power is making it possible to design new polymers with tailored characteristics. Large, high value added market. Polymer-based advanced materials are enabling technologies for many electronic, biologic, and structural material applications.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000		X	

In advanced polymers, the U.S. was judged in 1986 to have a diminishing lead over Japan in research, and to be behind in product development.[35]

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Possible shortage of scientists and engineers. High cost of capital reduces the incentive to do research if one will not be able to afford to invest in production equipment.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Closely related to composites and other advanced materials. Design of polymers depends on supercomputers, software, and analytical instruments, chemical synthesis capability, etc.

POLICY ISSUES: Basic research funding, science and engineering education, and cost of capital.

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[35] National Research Council, Committee on Frontiers in Chemical Engineering, Frontiers in Chemical Engineering, Washington, National Academy Press, 1988, p. 70-71.

CRITICAL TECHNOLOGY: **Non-Linear Optical Materials**

DESCRIPTION: Materials whose optical properties change in a non-linear manner (such as from one stable phase to another) in response to stimuli.

WHY IS IT A CRITICAL TECHNOLOGY? Enables the development of many kinds of optical and optoelectronic devices, such as switches, for use in optical computers and other optical information devices.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		P	R
2000			

Research = R
Product = P

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Underinvestment by industry in R&D projects with long-term payoffs.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Solid state physics, optics, microelectronics.

POLICY ISSUES: Research funding (such as NSF's Lightwave Technology Program).

CRITICAL TECHNOLOGY: **Superconducting Materials and Fabrication Technology**

DESCRIPTION: High temperature and low temperature superconducting materials (ceramics and metal alloys, respectively) and associated process technologies.

WHY IS IT A CRITICAL TECHNOLOGY? High temperature superconductors would enable a wide range of electronics and energy applications, from faster digital devices to energy storage devices.

U.S. POSITION RELATIVE TO RoW:

B = basic research
A = applied research

	Lag	Par	Lead
1990	A		B
2000	A	B	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Japan is spending more on superconductivity research than is the United States, and companies are putting more effort into investigating commercial applications (source: DARPA, HTSC, 2/89)._Europe is doing very little.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on solid state physics, ceramics processing, electrical engineering, and surface science. Requires state of the art analytical instruments and processing.

POLICY ISSUES: DARPA funding. Factors affecting time horizons of U.S.. industrial R&D. Technology transfer from DOE and DOD laboratories. DOD procurement.

CRITICAL TECHNOLOGY: **Membranes**

DESCRIPTION: Thin, two dimensional structures designed to allow certain components of a mixture to preferentially pass through. Used in filtration, purification, and concentration of gases and liquids.

WHY IS IT A CRITICAL TECHNOLOGY? Many applications in chemical processing, waste management, artificial organs (such as kidneys or pancreases), and drug delivery. There is a large potential for improvements and growth.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Possible shortage of scientists and engineers.(?) High cost of capital makes it difficult to sustain R&D effort.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on analytic instruments, basic research in chemistry and materials.

POLICY ISSUES: Federal research support; science and engineering education; cost of capital.

CRITICAL TECHNOLOGY: **Precision Coating**

DESCRIPTION: Technologies for depositing thin layers of one material on another, such as various types of chemical vapor deposition.

WHY IS IT A CRITICAL TECHNOLOGY? Key aspect of the processing of many electronic, optical, and photographic materials. Examples include polymer coatings on silicon used in the manufacture of semiconductors and on optical fibers, and magnetic coating on polyester films in making magnetic tape.

U.S. POSITION RELATIVE TO RoW:

Techniques = T
Equipment = E

	Lag	Par	Lead
1990	E	T	
2000			

Source: NRC Frontiers in Chem E

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Weaknesses in U.S. electronics industry could weaken the U.S. demand for advanced coating techniques. High cost of capital inhibits investments. Fragmented U.S. equipment industry may be weak compared to more integrated Japanese competitors (?).

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on knowledge of surface chemistry. Related to semiconductor manufacturing equipment; may be critical for high-temperature superconductor manufacturing.

POLICY ISSUES: Cost of capital; R&D in related areas of science and technology.

CRITICAL TECHNOLOGY: **Precision Machinery**

DESCRIPTION: Precision machines and machine tools.

WHY IS IT A CRITICAL TECHNOLOGY? Essential for making chemical process equipment.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990	X		
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Weak U.S. machine tool industry. (See machine tool sectoral profile)

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on microelectronics, computers and software, numerical controls, and advanced materials.

POLICY ISSUES: (See machine tool sectoral profile)

CRITICAL TECHNOLOGY: **Supercomputers and software**

DESCRIPTION: High speed computers and software

WHY IS IT A CRITICAL TECHNOLOGY? They are powerful tools in the design of new molecules and materials and in the modeling of chemical reactions and processes. They make it possible to design and simulate the performance of many alternative configurations of a substance or process, greatly accelerating the design and testing process. [36]

U.S. POSITION RELATIVE TO RoW:

Computers = C
Software = S

	Lag	Par	Lead
1990		C	S
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: U.S. supercomputer industry is financially weaker than its Japanese competitors. Foreign targeting. Cost of Capital. (See computer industry sectoral profile)

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Dependent on microelectronics. DOD funding has been important. Closely related to product and process modeling; algorithms.

POLICY ISSUES: Export control; R&D funding for computers and software. Supercomputer network bill. (See computer industry sectoral profile)

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[36] Borman, Stu, "Improved Access to Supercomputers Boost Chemical Applications," Chemical and Engineering News, July 19, 1989, p. 29-37.

CRITICAL TECHNOLOGY: **Neural network technology**

DESCRIPTION: Computers designed to mimic the brain's network of neurons that are programmed to "learn" from data to recognize patterns.

WHY IS IT A CRITICAL TECHNOLOGY? The strength of neural networks is in pattern recognition, which is a weakness of traditional computers and software. Neural networks thus extend the use of computers into new areas, such as identifying optimum production conditions and deviations from acceptable conditions.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000		X	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Need greater university research. Underinvestment by U.S. companies relative to foreign companies.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Closely related to artificial intelligence, computer hardware and software, and microelectronics.

CRITICAL TECHNOLOGY: **Artificial Intelligence**

DESCRIPTION: Electronic and electromechanical systems incorporating knowledge-based control systems. Includes expert systems, intelligent machines and process controls.

WHY IS IT A CRITICAL TECHNOLOGY? Expert systems can aid both design and operations by providing encoded expert advice. Can improve analysis and interpretation of data. Can also be used to help transfer expert knowledge from one part of the corporation to another.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Shortage of artificial intelligence researchers and engineers. Dedicated efforts in Europe and Japan.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Related to databases, computer hardware and software, neural networks, biological and cognitive sciences. DOD funding and applications are important.

POLICY ISSUES: R&D funding; science and technology manpower issues.

CRITICAL TECHNOLOGY: **Advanced Sensors**

DESCRIPTION: Sensors for process monitoring and control. Includes electronic, optoelectronic, acoustic, and biological sensors.

WHY IS IT A CRITICAL TECHNOLOGY? Realtime knowledge of the status inside chemical processes is essential for maintaining over the processes, in order to increase quality and productivity.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Weaknesses in electronics industry could cause weaknesses in sensors.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on microelectronics, biotechnology, optoelectronics. Advanced sensors are essential for process monitoring and control.

POLICY ISSUES: Technology transfer from DOD/DOE labs.

CRITICAL TECHNOLOGY: **Advanced Process Control**

DESCRIPTION: Methods and technologies to collect, interpret and communicate information on chemical processes and to use this information to control operations to monitor and adjust processes to keep the output within specifications.

WHY IS IT A CRITICAL TECHNOLOGY? Can greatly improve quality and productivity, and lower wastes and production costs. By reducing waste, it can also reduce the capital costs for processing the waste streams.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: High cost of capital makes process improvements more difficult. Weaknesses in electronics sector could weaken U.S. in process control technology.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on sensors, computers and software. Interrelates with process design and simulation technologies. Also depends on mathematical modeling and control theory.

POLICY ISSUES: Cost of capital; R&D support for related technologies.

CRITICAL TECHNOLOGY: Analytical Instruments

DESCRIPTION: Instruments for observing and measuring characteristics of chemicals and materials. Includes nuclear magnetic resonance spectroscopy, electron microscopy, etc.

WHY IS IT A CRITICAL TECHNOLOGY? State of the art analytical instruments are necessary for state of the art science and engineering. Advances in analytic instruments often lead to advances in science that make possible new technologies.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: U.S. instrument makers are generally competitive, but do not produce some leading edge instruments. In the long run, they may lack the resources and industry structure to compete with larger and more integrated competitors.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Analytical instruments are closely linked to microelectronics and computers.

CRITICAL TECHNOLOGY: Environmental Technologies

DESCRIPTION: Inherently safer and less polluting products and processes, recycling technologies, and waste management processes. Examples include the chemical industry's search to replace chlorofluorocarbons, and the development of biodegradable starch-based polymers, inherently safer and less polluting plants that produce less waste and contain reduced inventories of hazardous materials. Other critical environmental process technologies include those to treat wastes to make them less toxic, and technologies to recycle wastes.

WHY IS IT A CRITICAL TECHNOLOGY? Global concern over the environment is leading to increasingly stringent regulations is causing a shift towards biodegradable, recyclable, or otherwise environmentally benign products.. Waste management and cleanup is a large growth industry because of inadequate past waste disposal practices. Companies that have cleaner products and processes can capture large market (such as replacements for CFCs) and can have a better public image.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Regulations that do not permit innovative ways of meeting the same goals. Short term industry view that resists change. Confrontational relations between industry, government, and public interest groups that do not allow optimum solutions to problems. High costs of capital. Shortage of skilled researchers and engineers.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Improved process design and control, catalysts, biotechnology, membranes, and synthesis all contribute to improved environmental technologies.

POLICY ISSUES: Affect of regulatory environment on innovation. Cost of capital. Federal R&D funding.

CRITICAL TECHNOLOGY: **Process and Product Modeling**

DESCRIPTION: Mathematical models to describe and explore the behavior of chemicals from the molecular scale to the processing plant scale.

WHY IS IT A CRITICAL TECHNOLOGY? Mathematical models run on computers make it possible to simulate the behavior of systems without physically creating the systems. It allows designers to explore many more possibilities while conducting fewer expensive tests and demonstration projects.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: If the U.S. lost its lead in supercomputers, it would hurt the U.S. lead in software and modeling.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Computers and software; applied mathematics.

POLICY ISSUES: R&D funding; scientific manpower issues.

III. THREATS TO U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

High Capital Costs

The United States has a higher cost of capital than many other industrialized countries, especially Japan and West Germany.[37] This discourages investment in R&D projects whose expected payoff is years away, and discourages investment in capital-intensive technologies. Although there are indications that the cost of capital in Japan and Germany has gone up,[38] those countries still enjoy an advantage.

The United States has an R&D tax credit that is intended to provide an incentive for R&D. This tax credit applies to incremental increases in R&D, and therefore benefits companies whose R&D budgets are growing. Thus it provides a greater benefit to small, rapidly growing companies than to large, established companies. The tax credit has not been made permanent, and the uncertainty about its future prevents companies from counting on it in their long-term planning. The Bush Administration proposes to make the R&D tax credit permanent, which would enable companies to incorporate it in their plans.[39]

In addition to its lower overall costs of capital, Japan has several other programs to provide low cost financing for R&D. One such source is the Japan Key Technology Center, which provides capital investment to organization established for cooperative R&D, and provides interest-free loans for R&D. Another source is the Japan Development Bank, which provides low-interest financing for the development and commercialization of technology.[40] Japan also has an R&D tax credit similar to that of the United States.

Product Liability

The U.S. legal system provides higher and more uncertain awards to plaintiffs than do the legal systems of other countries. Strict product liability (not requiring any judgement of negligence) and the tendency of juries to award huge punitive damages is seen as providing a disincentive for innovators to produce new products.[41] Pharmaceutical companies, have discontinued research in areas such as contraceptive research because the potential liabilities are too great. Monsanto decided not to market a safe and biodegradable asbestos substitute because of the risk of being drawn into asbestos-related litigation.[42] The Bush Administration has made product liability reform a priority for promoting the competitiveness of U.S. industry.

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[37] McCauley, Robert N., and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital", FRBNY Quarterly Review (Federal Reserve Bank of New York), Summer 1989, p. 7-28. The difference is caused by differences between the three countries in savings, in the relation of banks to industry, and in the government responses to corporate distress.

[38] Brauchli, Marcus W., "Japanese Access to Cheap Money Tightens, Blunting Crucial Edge," The Wall Street Journal, January 26, 1990, p. A12.

[39] U.S. Executive Office of the President, Office of Science and Technology Policy, "Science and Technology in the President's FY 1991 Budget," (Press Statement) Washington, January 29, 1990. p. 4.

[40] Agency of Industrial Science and Technology, 1988, Tokyo, Ministry of International Trade and Industry, 1988.

Uncertain Demand for Advanced Materials

Developers of advanced materials are reluctant to invest in them unless they are confident of the market for the materials. Users of advanced materials are reluctant to develop products that require advance materials until they can be sure of adequate supplies of a product at a specific prices. Relations between customers and suppliers tend to be less cooperative in the United States than in some other countries, particularly Japan, which inhibits the ability to invest in technologies. The restrictive antitrust climate in the United States inhibits companies from cooperating in technology development.

Trade Policy and Export Controls

A major trade-related impediment to technology development in the chemical industry is export controls designed to prevent technologies from reaching eastern block countries. The U.S. imposes tighter controls on technology exports than do many competitors, resulting in delays in U.S. sales and added costs of doing business. These controls affect a number of technologies, including advanced materials and biotechnology.

Environment Regulations

The U.S. environmental, safety, and health regulatory environment is one of the most stringent in the world. This has both negative and positive effects on competitiveness and on technology development in the industry. On the one hand, strict regulations divert human resources and capital from improving products and productivity to pollution control and regulatory compliance activities. They can increase U.S. production costs and cause companies to move operations to countries where regulatory compliance costs are lower. They also tend to shift the focus of product and process development toward more environmentally benign technologies, and encourage companies to get out of areas where the regulatory burdens are higher.

On the other hand companies that have environmentally better technologies can prosper as environmental standards become tighter around the world. If regulations that encourage the development of innovative technologies, they can be a powerful incentive to innovation, and can encourage companies to invest more in R&D. Tough but competent regulation can also increase public confidence in the industry. It should also be noted that the U.S. regulatory environment is not always more stringent than those in other countries. U.S. regulations regarding biotechnology, for example, are currently less restrictive than those in the European Community. More cooperation is needed between industry and government in designing regulations to achieve the desired effect with a minimum impact on the competitiveness of industry.

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[41] Mahoney, Richard J. and Stephen E. Littlejohn, "Innovation on Trial: Punitive Damages Versus New Products," Science, December 15, 1989, p. 1395-1399.

[42] Ibid.

Intellectual Property

The existence of strong U.S. patent laws has been a major benefit for the chemical industry. There are several intellectual property issues relevant to the chemical industry. One is **patent piracy**. U.S. pharmaceutical companies alone estimate that they lost $2 billion to patent pirates in 1988.[43] The chemical industry, particularly the pharmaceutical and pesticide producers, would benefit from stronger international enforcement. Another is the **length of patent protection**. For products that undergo a lengthy regulatory approval process, such as drugs and pesticides, the regulatory approval time eats into the period of patent protection. Drug makers can extend the period of patent protection to make up for the time lost in the regulatory approval process, while pesticide makers cannot. Pesticide makers tend to support patent term restoration for pesticides. A third is **uncertainty in biotechnology patent law**. Many patent issues concerning the patentability of new life forms and processes have not been fully sorted out by the Patent Office and by the courts. The uncertainty makes it more difficult to invest in biotechnology research. Strengthening international patent protection under the General Agreement on Trade and Tariffs (GATT) is a Bush Administration priority.

Education

The chemical industry is concerned about the availability of technically trained people. The numbers of people receiving bachelor's degrees in chemistry and chemical engineering have been declining. The numbers of people receiving Ph.D. degrees in chemistry and chemical engineering have been increasing slightly, but at a much slower rate than R&D in the industry has been increasing.[44] At the pre-college level, American students score poorly compared to students in competitor countries in standardized math and science achievement tests.

Foreign Targeting

Several foreign countries are targeting advanced materials and biotechnology development for competitiveness. A National Academy of Sciences panel found that the policies of Japan, Korea, Germany, and France provided a competitive advantage to those countries.[45] Similarly, Japan, German, France, and the United Kingdom all have policies directed at promoting commercial biotechnology.[46]

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[43] U.S. Department of Commerce, International Trade Administration, 1989 U.S. Industrial Outlook, Washington, U.S. Govt. Print. Off. 1989. p. 16-1

[44] Rawls, Rebecca L., "Facts and Figures for Chemical R&D," Chemical and Engineering New, August 21, 1989, p. 55.

IV. FACTORS SUPPORTING U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

A Strong Industry Focus on Technology

The chemical industry was born in research laboratories and has always been a technology based industry. Its manager and leaders have usually had strong technical backgrounds, and innovation has always been part of the business. Unlike some industries, it has been dominated by scientists and engineers rather than marketing or financial people. With this background, the industry has found it easier to stay at the forefront of technology, and has been more willing to embrace change than other industries.

A Strong Emphasis on Process Engineering

In the chemical industry, product and process technology are closely linked. The chemical industry has never neglected process engineering, and chemical engineering is a well-established academic discipline. In this regard, it differs from other manufacturing industries, that have often tended to underemphasize process technology. The emphasis on process technology is a reason why the U.S. chemical industry has remained competitive, even in the commodity chemical parts of the market.

Strong U.S. University R&D and Effective University-Industry Linkages

Advances in chemistry, chemical engineering, and related biological and material science can directly benefit the chemical industry. The chemical industry benefits directly from the strong U.S. research universities.

Federal support for chemical research (not development) in all agencies was $677 million in 1988, up from $606 million in 1984. Support for chemical engineering research was $244 million, up from $144 million in 1984.[47] $291 million of the chemistry research and $60 million of the chemical engineering research funding went to universities. These numbers, although small compared to chemical industry R&D spending, are a significant part of basic chemical research.

The Federal government also spends a substantial amount on research in other fields related to the chemical industry, including biological and agricultural sciences ($4.6 billion in 1988), environmental sciences ($1.6 billion), and metallurgical and materials engineering ($462 million).[48] Federal R&D spending is particularly important to the U.S. technical base in biotechnology.

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[45] National Research Council, Committee on Material Science and Engineering, Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials, Washington, National Academy Press, 1989, p. 186-205.

[46] U.S. Congress, Office of Technology Assessment, Commercial Biotechnology: An International Analysis, Washington, U.S. Govt. Print. Off., January 1984., p. 475-485.

[47] Rawls, Rebecca L. "Facts and Figures for Chemical R&D", Chemical and Engineering News, August 21, 1989, p. 28-61.

Defense and Space R&D and Procurement of Advanced Materials.

Department of Defense (DOD) and NASA procurement of advanced composites for aerospace has given U.S. companies a market, and a technological lead, for these materials. On the other hand, DOD procurement rules and export controls (described later) hurt the commercialization of technology, and DOD involvement in chemical warfare probably has a negative effect on the public image of the industry.

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[48] National Science Board, Science & Engineering Indicators - 1989, Washington, U.S. Govt. Print. Off, 1989. p. 280 (basic research funding) and p. 282 (applied research funding).

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

This research paper was prepared by Council Senior Associate David W. Cheney. Alexander MacLachlan of Dupont, Dan Irwin of FMC Corporation, and Virginia Weldon of Monsanto provided valuable wisdom and information.

The Council would like to thank Pfizer Inc. and NMTBA/The Association for Manufacturing Technology for their assistance in publishing the profiles.

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ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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* * *

A COMPETITIVE PROFILE OF THE COMPUTER AND SOFTWARE INDUSTRY

Research Paper for

GAINING NEW GROUND:

TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future.*

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling and $20 for *Gaining New Ground* plus $2.50 postage and handling.

Computer Systems Industry

SECTORAL PROFILE

Executive Summary

Industry Characteristics

The U.S. computer systems industry and its supporting infrastructure have been the source of innovative products that have had a major impact on capabilities and productivity of virtually every segment of the economy. The rapid rate of technological change that has characterized computer systems continues unabated. Performance of computers has improved significantly, even as prices continue to drop. Computer systems, which started as isolated central processing units, have grown into interconnected systems of processors, terminals, servers and work stations. Communications, human factors and manufacturing technologies have joined traditional hardware and software technologies as important competitive factors in the industry.

Changes in the nature of computer systems have brought about transformations in the industry's participants as communications, desktop computers and new peripheral equipment have gained in importance. Work station computing capacity now rivals that of many mainframe processors, and the role of mainframes in some systems has turned from processing data to database and communications management. The minicomputer segment of the market, once the source of utility processors for a wide range of modest applications has been caught in the squeeze between mainframes and desktop capabilities.

The U.S. computer systems industry remains strong in many respects, and has responded effectively to shifts in the business. New firms have arisen to exploit new technological developments, and historically strong firms have adapted to new business opportunities. The same cannot be said of the subsystem and component companies supporting the industry, which have weakened with time.

The process required to develop and produce computer systems in the United States involves a web of relationships among an extremely diverse set of component industries that include the computer equipment industry, software industry, tool and test industry, semiconductor manufacturing industry and peripherals and components industry. For the process to succeed in producing cost-effective, technologically-advanced U.S. computer systems, the network of relationships cannot be broken. Weakness or damage to any critical component of the web would render it too weak to support the competitive position of other manufacturing and support industries that depend upon U.S. high technology products to be competitive. If one or more of the essential component industries does not perform adequately or ceases its operations in the United States, the resulting global imbalance of technology may cause significant strategic damage to the U.S. computer industry. This paper examines the health of the web by reviewing the status of specific existing and emerging technologies that are critical to the maintenance and growth of the U.S. computer systems industry.

Almost nonexistent 30 years ago ($1.5 billion in 1960) the manufacturing and servicing of computer systems had become a major sector of the U.S. economy, with worldwide shipments of $164 billion of hardware and services in 1989. U.S. computer systems firms employed about 587,000 workers in the United States in 1989 and a similar number abroad. Computer industry employment accounts for 1.4% of U.S. manufacturing workers and 0.6% of all U.S. workers. The balance of trade in computer equipment, although it has declined significantly over the past decade, has remained positive through 1989. ($836 million in 1989, compared to about $7 billion in the early 1980's.)

Growth in the industry's output, employment, exports and innovation has been leading the advance of the economy over the past two or more decades. Expenditures on R&D by the computer systems industry as a percent of sales is among the highest of all American industry.

Critical Technologies

Critical technologies for the Computer Systems Industry include architecture, software and hardware technologies necessary to produce computer systems as well as the manufacturing processes needed to produce them.

The critical technologies are:

- **Processor Architecture** that determines the inherent capabilities of a computer processor.
- **Networks and Communications** technology needed to connect individual processors and servers into interactive networks that form the computer systems of the future.
- **Software Engineering** technology needed for efficient, error-free conception, design and production of complex instruction system, language and application products.
- **Application Technology** to efficiently produce attractive solutions to user problems.
- Optical and magnetic information **Storage** technology to improve such important system-related characteristics as accessibility, economical size and permanence of memory.
- **Manufacturing Technology** for production of inexpensive, high quality computer hardware.
- **Integrated Circuits Fabrication Equipment and Facilities** that underlie the microelectronic components industry that, in turn provides much of computer systems' hardware function.

- **Microelectronics** technology for components that determine the hardware performance of computer systems.

- **Electronic Packaging** that provides housing, interconnection and cooling for microelectronic "chips" within a computer system.

- **Database Systems**, the architecture of computer-based information management.

- **Human Interface** technology to bring complex computer capability closer to human users.

- **Operating Systems** that provide the environment for individual applications programs.

- **Visualization** technology for efficient presentation of complex data to humans.

- **Display** technology for terminals, workstations, and personal and portable computers.

- **Hardcopy Technologies** to produce document forms of computer output.

- **Optoelectronics** technology for future broadband data transmission within computer systems.

Critical Issues

U.S. computer systems firms are still the dominant producers in world computer equipment and software markets. To ensure that this dominance continues, U.S. firms must have the capability to exploit technological innovation to produce quality computer systems that are responsive to market needs. Key to the industry's success is a continuous self-evaluation process in which global positions are reassessed. Over the past decade, a number of serious challenges have faced the U.S. computer industry in some critical technology and product sectors. These foreign challenges have also occurred in a broad range of high growth and mature electronic products and technologies, many of which U.S. producers no longer dominate.

To understand the importance of the challenges presented by this changing competitive environment to the future success of the U.S. industry. senior research officials of the eleven member companies of the Computer Systems Policy Project, which was established in 1989 to identify and advocate a public policy agenda for the U.S. computer systems industry, reviewed a wide range of critical technologies. This review, which is summarized in this paper, leads to the following conclusions:

- The United States leads the rest of the world in highly creative technologies such as software; however, these less capital intensive technologies have recently been targeted by off-shore competitors who are undertaking extensive R&D efforts to close the gaps.

These technologies are software engineering, applications technology, networks and communications and computer (processor) architectures.

- The United States currently lags the rest of the world in the more fundamental and capital intensive technologies, such as microelectronics, integrated circuit fabrication equipment and facilities, electronic packaging and manufacturing technologies.
- The United States also lags the rest of the world in many product-related technologies such as printers and optical storage.

While the overall international competitiveness of the industry is dependent on a wide range of factors, a narrower group of factors is especially relevant to maintaining or regaining U.S. leadership in the nine technologies identified above as critical to the U.S. computer systems industry. These factors are:

- Business Environment - Capital investment, critical mass, large market size, and intellectual property protection.
- Research, Development and Manufacturing - State of the art manufacturing, applied research & development, basic research, and linkages between research, development and manufacturing.
- People/Culture - Skilled personnel, quality, and cooperation within the private sector.

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Sectoral Profile

The Computer System Industry

I. INDUSTRY CHARACTERISTICS

Definition

Innovative products of the U.S. computer systems industry and its supporting infrastructure that have had a major impact on capabilities and productivity of virtually every segment of the economy. The rapid rate of technological change that has characterized computer systems continues unabated. Performance of computers has continued to improve significantly throughout the life of the industry, even as prices have dropped. Computer systems, which started as isolated central processing units, have grown into interconnected systems of processors, terminals, servers and work stations. Communications, human factors and manufacturing technologies have joined traditional hardware and software technologies as important competitive factors in the industry.

The nature of computer systems has changed and that shift has been reflected in the make-up of the industry's participants as communications, desktop computers and new peripheral equipment have gained in importance. Work station computing capacity now rivals that of many mainframe processors, and the role of mainframes in some systems has turned from processing data to database and communications management. The minicomputer segment of the market, once the source of utility processors for a wide range of modest applications has been caught in the squeeze between mainframes and desktop capabilities.

The U.S. computer systems industry itself remains strong. It has responded effectively to shifts in the business. New firms have arisen to exploit new technological developments, and historically strong firms have adapted to new business opportunities. The same cannot be said of the infrastructure supporting the industry, which has weakened with time.

The computer systems industry is engaged in the production, distribution and servicing of electronic computers, data storage devices, controllers, terminals and other peripheral equipment, software and services.

Manufacturing and servicing of computer systems has become a major sector of the U.S. economy. Worldwide shipments of hardware and services have grown from $1.5 billiion in 1960 to $164 billion in 1989. U.S. computer systems firms employed about 587,000 workers in the United States in 1989 and a similar number abroad. Computer industry employment accounts for 1.4% of U.S. manufacturing workers and 0.6% of all U.S. workers. Exhibit 1 shows the size of the industry in relation to general economic activity.

These figures vastly underestimate the degree to which computers have penetrated the global culture. It is hard to conceive of any sector of the economy or aspect of society that has not been affected by the "computer revolution."

The process required to develop and produce computer systems in the United States involves a web of relationships among an extremely diverse set of component industries. The component industries include the:

- **Computer Equipment Industry,** which designs, builds, programs and services information processing systems, ranging from tiny single-purpose or "dedicated" boxes to supercomputers. It integrates the products of all the other industries and, thus, can be considered to sit atop the production pyramid.
- **Software Industry,** which conceives and writes tens of thousands of program packages involving billions of lines of code -- individual statements of instructions. These programs enable computers to do useful work, including the design of more complex chips and systems. These programs range from standard operating systems governing the functions of one computer or a network of computers, to specialized programs for applications such as financial forecasting, database management, scientific research, and computer-aided design, engineering and manufacturing. Software can be incorporated into computer hardware in the form of fixed memory or sold separately on disk or tape.
- **Peripherals and components industry**, which designs and builds a wide range of equipment essential to the computer business. This includes displays, disk drives, printers, tape drives, and special components from scanners to audio devices.
- **Semiconductor manufacturing industry,** which designs and produces "chips" and modules. Some are proprietary to a single systems manufacturer. Some chips are purchased or licensed by systems manufacturers, who package and interconnect them in many innovative ways to bring computer systems to market.
- **Tool and test industry,** which makes the extremely complex processing and manufacturing equipment used by computer systems and semiconductor manufacturers to design and build memory and logic devices and the technical equipment needed to test individual circuits as well as complete systems.

Each of these high technology electronics industries makes an essential contribution to the development of a computer system or other computer-containing product. The industries are linked technologically and economically and individual companies must develop close working relationships across industry lines. There must be extremely close cooperation between individual suppliers and users. The design and functional capability of any new data processing system traces inexorably back to its software, the design of its component parts, and whether those parts can be manufactured economically.

Firm and Plant Characteristics

There are 20,847 firms and 23,334 establishments primarily engaged in the provision of computer equipment and related services in the United States. A breakdown of the industry structure for 1987 is shown in Exhibit 2.

The industry contains many small firms (19,869 of the 23,334 establishments employ fewer than 20 people), although most production is accounted for by large firms. Despite their small share of the total output, the role of small firms in the industry's development has been substantial and critical. Small firms have been the source of many key technological advances in computer products over the past 30 years, often resulting from the work of scientists and engineers who left large companies to pursue their interests in firms of their own.

Closely related to computer systems firms are data processing services and computer renting and leasing companies, which in 1987 had 18,107 establishments, $43.5 billion in revenues and employed 331.2 thousand people. These activities would be virtually impossible without the products of the computer systems industry.

Relationship to the Electronics Sector

Because the technical and manufacturing processes used to produce computers are also used to produce other electronic products, it is becoming increasingly difficult to distinguish between a "computer-like" function of an electronic product (e.g., automobile engine control electronics, automobile anti-lock braking system, a facsimile machine, a VCR) on the one hand, and the functions in a desk top computer on the other. Thus, the products and services of the computer systems industry are closely related to those of the electronics industry.

Examples of common technologies include:

- Emerging technologies, such as digital optics, digital microelectronics and digital magnetics, that are soon to be used in a wide range of products such as digital facsimile machines, printers, high-definition television (HDTV), and home communication and information systems;

- Display technologies, such as cathode ray tubes, and LCD screens, that are used in computers of all kinds, typewriters, facsimile machines, copiers and other business equipment, laboratory and medical instruments of all kinds, toys and games, communications equipment, and automobiles and other transportation equipment and services;

- Semiconductors and related devices, such as microprocessors, that are used in virtually all computers, computer peripherals, electronic instruments, medical equipment, communications equipment, automotive computer systems, VCRs, camcorders, compact disc players, microwave ovens, machine tools, and other consumer and industrial electronics; and

- Circuit board manufacturing technologies that are used in computers, televisions, kitchen devices, tools, automobile components and instruments and business equipment of all kinds.

Thus, in a broad sense, the computer systems industry can be considered a part of the electronics sector. In 1989, the electronics sector, including materials, components, data processing services and other advanced technology services, had revenues of over $433 billion (of which about $208 billion was for manufacturing) and 2.6 million employees. As shown in exhibit 3, the revenues and employment in the U.S. computer and electronics sectors are comparable to those of other major industry sectors.

The Critical Role in Downstream Industries

Computer system products are necessary and critical components of virtually all modern manufacturing and service industries. Communication systems, business equipment, medical and scientific instrumentation, consumer electronics and computer systems increasingly rely on a common set of technologies and components. These industries have become as dependent on computer industry components as they are on metal, plastic, glass and rubber for manufacturing. It is difficult to think of significant technical advances over the past two decades that would have been commercialized without computer systems industry inputs.

- Personal computers have become a common tool in most business and scientific applications in the U.S.. Ninety percent of PCs are sold for business and scientific applications[1].

- The average automobile includes about $800 of electronics, including computer components.

- Office equipment, such as electronic typewriters, facsimile machines,copiers, cellular and other types of telephones, all have computer-like components that are vital to their operations.

- Services, which has become the dominant sector of the U.S. economy, is the largest consumer of computer products and services[2]. Services accounted for 52% of the GNP in 1989 and is highly dependent upon the computer systems industry for its current operations and productivity improvement. The changes brought about by airline reservation and scheduling systems, air traffic control systems, finance and insurance industries and word processing have increased the productivity of the service sector and, indeed, have made possible services that were heretofore impracticable.

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[1] U.S. Industrial Outlook, 1990, pp. 30-7

[2] Data Resources Inc., The Impact of the Computer Software and Services and Computer Hardware Industries in the U.S. Economy, Prepared for ADAPSO (the Computer Software and Services Industry

- Today's highly automated and high-capacity. high-speed telecommunications industry would not exist without computer equipment and computer-like components.

Computer systems have become more than a tool to improve productivity; they have become a major force that molds the business environment. In addition to contributing to the automation of jobs, (e.g., computerized accounting systems), computers are fostering business process redesign (e.g., replacing paper with electronic funds transfers), business network redevelopment (e.g., linkages between suppliers and customers) and business scope changes (e.g., brokerage houses becoming bank-like institutions). The Institute for the Future predicts that, by 1995, 90% of American white-collar workers will have a computer at their disposal[3].

The Critical Role in National Defense

Most of the sophisticated weapons in the U.S. arsenal would be impossible without computer system and electronic components. Of 22 technologies recently identified by the Defense Department as critical to the national security and the long-term qualitative superiority of U.S. weapons systems, all are dependent on computer systems. Computer technology has dramatically increased the reliability, dependability and availability of electronic components by reducing their physical size and power requirements, while also providing economies of scale for cost-effective production of large quantities. Microelectronics technology, in particular, has a pervasive effect on virtually every current or future weapons system. Miniaturization technologies allow major modifications of current weapons platforms (e.g., the creation of inherently aerodynamically unstable aircraft that are stabilized by on-board microprocessors, as on the F-16). In addition, the ability to build in self-test circuitry promises to greatly reduce maintenance problems and improve overall systems reliability. Increasing circuit complexity will allow major expansion of operational capabilities for reconnaissance, surveillance and target acquisition and command, control and communications (C3).

- Silicon technology enables very high-speed integrated circuits (VHSIC) used in high performance signal processing applications.

Association), (1986)

[3] "Information Technology," The Economist, June 16, 1990, following page 58.

- The notions of "smart hulls" for submarines and "smart skins" for aircraft are dependent on high-performance parallel computing systems.

- Computer simulation and modeling can be applied to every major DOD weapons development program to reduce design and production cost, improve performance, diagnostics and maintenance, and assist in better and faster training of personnel and improve command and control of the battlefield.

- Other military applications include:

    - Artificial intelligence applications such as self-guided vehicles, intelligence/robotics, sensitive radars, automatic targeting recognition and data fusion;

    - Digital imaging technologies applied to sensitive radars and automatic target recognition;

    - High density data storage using optical techniques; and

    - Optoelectronics for communications and signal processing.

The use of computer technology in defense systems has become so pervasive that software and maintenance costs are estimated to be as much a 10 percent of the entire budget of the Defense Department[4].

INTERNATIONAL COMPETITIVE POSITION

In 1989, U.S. computer equipment exports totalled $22.4 billion, 6% of total U.S. merchandise exports. Related products such as telecommunications equipment, semiconductors, office and business machines, totaled $19.4 billion. Thus, exports of all four related product groups were $41.8 billion, or 11.6% to total U.S. merchandise exports.

The U.S. balance of trade has deteriorated substantially over the past decade. The balance in the computer industry, although it has also declined substantially, has remained positive through 1989. Total U.S. merchandise exports grew at a compounded average annual rate of 5.4% between 1980 and 1989, compared to import growth of 7.3% annually. Total merchandise trade had a deficit in 1989 of $119.8 billion.

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[4] Department of Defense, Critical Technologies Plan, March 15, 1990, p. A-20

Annual growth of exports and imports of computer products averaged 12.7% and 38.3% respectively, over the period. The balance of trade in computer equipment was $836 million in 1989, compared to about $7 billion in the early 1980s.

Because each component of the industry (test and tools builders, chip and module designers, peripherals manufacturers, software developers and systems producers) is dependent upon the other's contribution to the end product, the computer system, the survival of each element is critical to all other elements in the web. For the process to succeed in producing cost-effective, technologically advanced U.S. computer systems, the complex web of relationships cannot be broken. If one or more of the essential component industries does not perform adequately or ceases its operations in the United States, the resulting global imbalance of technology may cause significant damage to the entire U.S. computer industry.

However, the industry historically has not viewed itself in such strategic terms. Rather, the industry perceived itself as entrepreneurial -- over half of the 3,500 member companies of the American Electronics Association are less than 10 years old and nearly three-fourths of its member companies have fewer than 200 employees -- with little evidence of formal cooperation within the industry. This small, independent firm perception led to an operating style that was oriented to the domestic market, favored short time horizons and viewed the transformation of basic science into product development as a disjointed process. The "not invented here" syndrome best characterized the industry's operating style. As previously demonstrated by the strong leadership of the industry since World War Two, this perception and resultant operating style served the industry well when the United States held a dominant position in global markets, when R&D costs were not escalating, when massive amounts of capital investment were not required to maintain a competitive manufacturing capacity, and when foreign competitors were not as well organized.

Today the U.S. computer industry finds itself in an intensely competitive environment. While U.S. firms are still the dominant producers in world computer equipment and software markets, the U.S. share of world computer system sales, according to Datamation magazine, fell from 81% to 61% from 1983 to 1989. Japan's share nearly tripled from over 8% to 22% and Europe's share increased from 10% to 15%. In the U.S. market, the share supplied by U.S. firms decreased from 81% to 66% during this period.

This decline is due to both increases in production in the rest of the world and a weaker dollar over this time period. The decrease in domestic production of electronics products has been even greater. Other indications of the changed international environment for the U.S. computer systems industry are:

- The number of U.S. companies, according to Datamation magazine, among the top 100 computer systems firms in the world decreased from 72 to 62 from 1983 to 1989. Eight Japanese companies and two European companies were added to the list.

- Prior to the late 1970s, U.S. computer imports were virtually nonexistent. By 1989, sales in the U.S. market of foreign-made computers and related equipment were $21.6 billion, or 36% of the U.S. market.

- The U.S. computer systems industry has become substantially dependent on Japanese producers for components such as semiconductors. 70% of U.S. merchant semiconductor consumption was supplied by foreign firms.

Increased foreign competition has occurred in a broad range of products -- both in high technology and moderate to low technology products. Exhibit 4 demonstrates the changes in market share that U.S. producers have experienced in many of the high growth electronic products and technologies. Although U.S. computer systems firms have maintained high worldwide market shares in networking, software and supercomputers, foreign competitors, especially the Japanese, are undertaking R&D efforts in each of these technologies.

An indication of Japanese and other foreign efforts in R&D are the trends in the number of U.S. patents awarded to foreign and U.S. inventors:

		Percent of Inventors From:		
Year	Total U.S. Patents Granted	U.S.	Japan	All Other Countries
1970	64,429	73%	4%	23%
1975	72,000	65	9	26
1980	61,819	62	11	27
1985	71,661	55	18	27
1988	77,924	52	21	27

Source: National Science Board, Science and Engineering Indicators - 1989, p.356.

To ensure its continued capability to exploit technological innovation to produce quality computer systems that are competitive and responsive to market needs, the industry must continuously evaluate its relative global position. To be useful and accurate, such evaluations should focus on the identification and exploitation of the specific technologies and issues that are critical to continued competitiveness of the industry over the next decade.

II. CRITICAL TECHNOLOGIES

Linkage of Innovation to U.S. Economic Performance

Growth in the industry's output, employment, exports and innovation has been leading the advance of the economy over the past two or more decades. Growth in shipments of computer products has averaged 11.7% over the past 10 years, compared to 4.9% for total U.S. manufacturing shipments. Similar growth rates have occurred for value added exports.

The contribution of the computer industry to the economy is far greater than these shipments indicate, because computer prices have dropped substantially over the period. A dollar buys more computing power today than previously. In October 1988, the Bureau of Labor Statistics (BLS) began publishing a set of computer industry price indexes. From October 1988 to October 1989, the experimental computer price index for general purpose digital computers fell 10% (Exhibit 5). Although longer-term historical price indices for computers are not available, microprocessor prices are available for comparative purposes. From 1981 to 1989, microprocessor chip prices declined 22.7%, an average annual decrease of 3.2%. During this period, the U.S. consumer price index increased 36% and the producer price index for finished goods increased 18%. Thus, in addition to rapid increases in the total dollar value of computers sold, the amount of computing power being installed per dollar has also grown substantially.

The growth of the computer systems industry is particularly beneficial to the U.S. economy because a large portion of its revenues is reinvested to add to the stock of capital in the economy. In addition, the industry contributes a large portion of the innovation and productivity improvement to the economy.

- In 1987 (latest data available), the computer systems industry accounted for 2.2% of total gross U.S. private domestic investment.

- Expenditures on R&D by the computer systems industry as a percent of sales is among the highest of all American industry. From 1985 to 1989, computer and business equipment industry R&D expenditures averaged about 10.6% of sales, while total U.S. R&D amounted to only 2.6% of GNP. The computer and business equipment industry R&D accounted for 11% of all U.S. R&D[5]. In 1989 alone, the computer industry reinvested $11.7 billion or 9% of sales in R&D, while the U.S. industry corporate rate was 3.4%[6].

- Productivity increases in the computer systems industry have been substantially greater than those of any other sector. For example, the average processing power of microcomputers, as measured by millions of instructions per second (MIPS) has been increasing 40% annually in recent years and the rate of improvement is expected to accelerate. Likewise, the increases for minicomputers and mainframes have been about 14% annually.[7]. This progress means that there is a substantial decrease in the cost of computing power.

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[5] CBEMA 1990 Databook, pp. 40-41.

[6] Business Week 1990 annual "R&D Scoreboard"

- Because most computer products are producer equipment, increased spending on these goods tends to improve productivity in the industries that use them. Shipments of computer products accounted for 19.6% of manufacturer shipments of equipment and defense products, including autos, in 1989, compared to 12.1% in 1979. The impact of this increase on productivity and output is even greater than these value of shipments indicate, because the real price of computer products declined substantially over the same period, i.e. the productivity of the computer systems themselves increased.

Critical Technologies

While U.S. firms continue their international leadership in some key areas of technology, serious international challenges have arisen in other areas. To understand international trends, it is useful to examine, in detail, the role and status of specific technologies. Two sources are used for this examination -- a recent Department of Commerce study of 13 key emerging technologies and a recent evaluation by the senior research officials of U.S. computer systems (CSPP member) companies.

Department of Commerce Study

A recent Department of Commerce study[8] found that, if current trends continue, before the year 2000, the United States will lag behind Japan in most emerging technologies and will trail the EC in several of them (See Exhibit 6). The emerging technologies of relevance to computer systems include materials (advanced materials, superconductors), electronics and information systems (advanced semiconductor devices, digital imaging technology, high density data storage, high performance computing, optoelectronics), and manufacturing systems (artificial intelligence, flexible computer-integrated manufacturing). Only in artificial intelligence and flexible computer integrated manufacturing is the United States expected to hold its own against Japan.

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[7] National Research Council, Keeping the U.S. Computer Industry Competitive, p. 26

[8] Emerging Technologies: A Survey of Technical and Economic Opportunities, 1990

Computer System Policy Project Evaluation

Over the past several months, the senior research officials of CSPP member companies undertook an evaluation to identify and rank in order of importance those technologies that are most critical to the future competitiveness of the U.S. computer industry. The research officials reviewed a wide range of sectors and ~~processes~~ from materials and microstructures to man/machine interfaces. This review resulted in the identification of sixteen technologies considered most important. These critical technologies are listed in Exhibit 7, along with a schematic of their logical relationship. A brief description of each of these technologies is given below.

The CSPP participants were asked to evaluate the importance of each of the sixteen technologies to the continued competitiveness of the U.S. computer systems industry. They were asked to summarize their evaluations in terms of a numerical value on a predetermined ordinal scale. The resulting data were then tallied. This analysis identified nine of the sixteen technologies as most important to the future competitiveness of the industry.

The in-depth analysis of the sixteen technologies undertaken by the research officials concluded that:

- The United States leads the rest of the world in highly creative technologies such as software, however, these less-capital intensive technologies have recently been targeted by off-shore competitors who are undertaking extensive R&D efforts to close the gaps. These technologies include:
    - Software engineering
    - Applications Technology
    - Computer (Processor) Architectures

- The United States lags behind the rest of the world in the more fundamental and capital intensive technologies. For example:
    - Microelectronics
    - Integrated Circuit Fabrication Equipment and Facilities
    - Manufacturing Technologies

- The United States lags in many product-related technologies. For example:
    - Optical Storage
    - Displays
    - Hardcopy Technology

Specific Critical Technologies

CSPP research officials identified fifteen "critical success factors" that profoundly affect the computer industry's ability to compete successfully in key technologies. In addition, they identified sixteen technologies upon which America's computer industry will depend in the next century. Nine of the sixteen technologies were deemed critical to the competitiveness of the industry in 1995.

PROCESSOR ARCHITECTURE

DEFINITION: Processor architecture, defined in its instruction set, determines the inherent capabilities of a computer processor. The instruction set portion of a computer processor describes the bit-level definition of the data and instructions the machine can process. The instruction set defines the machine-executable portions of the interface to which software is assembled, compiled and linked. Instruction sets can be organized into different types of architectures such as Complex Instruction Set Computer Systems (CISC), Reduced Instruction Set Computer Systems (RISC), superscalar, wide-word, multiprocessor, and massively parallel.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Applied Research and Development
- Basic Research
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Critical Mass
- Large Market Size
- Quality
- Collaboration among Academia, Government and Business
- Intellectual Property Protection

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently: Ahead

1995, Current Trend: Lead rapidly diminishing

1995, Best Case: Ahead

NETWORKS AND COMMUNICATIONS

DEFINITION: As computer systems have evolved from isolated processing centers to interconnected systems of processors, work stations and servers, ability to communicate large amounts of data quickly and without error has increased in importance. Networks allow computers to transmit and receive data. The technologies required to enable computer communications include: connecting devices (optical fiber, coax cable, microwaves, etc.), switches, controllers, routers, gateways, PBXs, communications protocols, tools for network management, network services, and security features.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Quality
- Applied Research and Development
- Collaboration among Academia, Government and Business
- Standardization and Standards
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Critical Mass
- Large Market Size
- State of Art Manufacturing
- Private Sector Cooperation
- Basic Research
- Intellectual Property Protection
- Reduced Risk For Large Emerging Market

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Lead rapidly diminishing
1995, Current Trend:	Behind
1995, Best Case:	Ahead

SOFTWARE ENGINEERING

DEFINITION: Software lies at the core of computer system capability. Efficient, error free software development has become a major goal of the computer systems industry as the complexity of software products has risen well above that of hardware portions of many systems. Software engineering encompasses software development processes and associated supporting technology, including development methods, programming languages, software development tools and environments, application integration environments and software components libraries.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Quality
- Applied Research and Development
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Private Sector Cooperation
- Collaboration among Academia, Government and Business
- Basic Research
- Standardization and Standards
- Intellectual Property Protection
- Research, Development and Manufacturing Linkages

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently: Ahead

1995, Current Trend: Lead Rapidly Diminishing

1995, Best Case: Ahead

APPLICATION TECHNOLOGY

DEFINITION: Application technology addresses the design and implementation of computer programs that solve user problems. Its principal components are methods for understanding the needs and tasks of user, methods for designing applications and for development environments and for tool kits to build applications easily.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Applied Research and Development
- Intellectual Property Protection
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Quality
- Collaboration among Academia, Government and Business
- Standardization and Standards

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Ahead
1995, Current Trend:	Ahead
1995, Best Case:	Ahead

STORAGE

DEFINITION: Physical mechanisms of information storage determine such important storage system characteristics as accessibility, economical size and permanence. Storage technology (Optical and Magnetic) includes magnetic and optical disks and tapes and their controllers for on-line backup and archival storage of data sets. Together, these systems store the vast majority of all data stored in digital form.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Critical Mass
- Large Market Size
- State of Art Manufacturing
- Quality
- Applied Research and Development
- Basic Research
- Research, Development and Manufacturing Linkages
- Skilled People

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Collaboration among Academia, Government and Business
- Standardization and Standards
- Culture Issues
- Reduced Risk for Large Emerging Market

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Lead Rapidly Diminishing
1995, Current Trend:	Behind
1995, Best Case:	Lead Rapidly Diminishing

MANUFACTURING TECHNOLOGY

DEFINITION: Hardware production is a critical factor determining competitiveness in computer systems and in many of its businesses. Manufacturing technology encompasses facilities, tools, information systems and infrastructures for production enterprises. These systems are essential for cost-effective, high quality and responsive production activities for a wide range of computer systems and underlying technologies. Elements of this technology include automated assembly, equipment and process tools, real time planning and control systems, modelling and decision technologies and the underlying information systems that facilitate use of the technology.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Critical Mass
- Large Market Size
- State of Art Manufacturing
- Quality
- Applied Research and Development
- Culture Issues
- Research, Development and Manufacturing Linkages
- Skilled People

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Private Sector Cooperation
- Collaboration among Academia, Government and Business
- Standardization and Standards

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Behind
1995, Current Trend:	Lead rapidly Diminishing
1995, Best Case:	Behind

INTEGRATED CIRCUITS FABRICATION EQUIPMENT AND FACILITIES

DEFINITION: Ability to produce the microelectronic components on which computer system hardware performance depends rests on the availability of increasingly sophisticated fabrication equipment and facilities for integrated circuit production. This critical technology includes both microelectronics fabrication equipment and production facilities with increasingly refined clean room environments, materials, process, equipment and lithography technology.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Critical Mass
- State of Art Manufacturing
- Quality
- Applied Research and Development
- Private Sector Cooperation
- Basic Research
- Research, Development and Manufacturing Linkages
- Skilled People

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Large Market Size
- Collaboration among Academia, Government and Business
- Standardization and Standards
- Intellectual Property Protection
- Culture Issues
- Reduced Risk for Large Emerging Market

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Behind
1995, Current Trend:	Lead rapidly Diminishing
1995, Best Case:	Losing

MICROELECTRONICS

DEFINITION: Hardware performance of computer system elements is determined more by the capabilities of the microelectronic component building blocks employed than any other single factor. Microelectronics technology includes silicon memory, logic and microprocessors, gallium arsenide memory, logic and photonic devices, superconducting logic and devices and computer assisted design (CAD) tools for design and test.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Critical Mass
- Large Market Size
- State of Art Manufacturing
- Quality
- Applied Research and Development
- Private Sector Cooperation
- Collaboration among Academia, Government and Business
- Basic Research
- Intellectual Property Protection
- Culture Issues
- Research, Development and Manufacturing Linkages
- Skilled People

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Standardization and Standards
- Reduced Risk for Large Emerging Market

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Behind
1995, Current Trend:	Lead rapidly Diminishing
1995, Best Case:	Behind

ELECTRONIC PACKAGING

DEFINITION: Electronic packaging and interconnection technology dominates the reliability of computer systems hardware and the capabilities of high performance computers such as supercomputers. Electronic packaging includes both encapsulation and interconnection technologies at the chip, board and board-to-board levels. Multichip packaging systems technology and next-generation printed circuit board technology provide volumetric compression of electronic functions and increase system performance. Design and test tools required to implement these technologies are fundamental to these new system components.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Critical Mass
- Large Market Size
- State of Art Manufacturing
- Quality
- Applied Research and Development
- Private Sector Cooperation
- Basic Research
- Research, Development and Manufacturing Linkages
- Skilled People

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Collaboration among Academia, Government and Business
- Standardization and Standards
- Intellectual Property Protection
- Culture Issues

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Behind
1995, Current Trend:	Lead Rapidly Diminishing
1995, Best Case:	Behind

DATABASE SYSTEMS

DEFINITION: Database technology is essential to computer-based information management. Information storage is at the heart of virtually all modern computer systems. Database technology encompasses the organization and characteristics of information storage. Key elements of database technology include data representation, storage, retrieval and update, semantic modeling and interpretation and maintenance of integrity.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Quality
- Applied Research and Development
- Collaboration among Academia, Government and Business
- Basic Research
- Standardization and Standards
- Intellectual Property Protection

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Ahead
1995, Current Trend:	Lead rapidly diminishing
1995, Best Case:	Ahead

HUMAN INTERFACE

DEFINITION: Human-computer interface technologies make it possible for human beings to get understandable information into or out of computers. These technologies can be as basic as a keyboard or mouse or as complicated as oral interaction -- or receiving a dynamically generated, animated video/audio presentation of on-line information in answer to a question. Human interface technologies include: graphical user interfaces, animation and full-motion video, optical character recognition (OCR), handwriting recognition, speech (synthesis and recognition) and natural language (particularly translation).

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Applied Research and Development
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Collaboration among Academia, Government and Business
- Basic Research
- Standardization and Standards
- Intellectual Property Protection

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Ahead
1995, Current Trend:	Lead Rapidly Diminishing
1995, Best Case:	Ahead

OPERATING SYSTEMS

DEFINITION: Complex computer systems require software that provides the environment for individual application programs. Operating system software -- underlying user applications -- that provides access and control of the underlying system architecture, facilities and hardware provides that environment. Operating systems are highly complex software routines that translate raw computer architecture into usable computer system capabilities.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Applied Research and Development
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Quality
- Private Sector Cooperation
- Collaboration among Academia, Government and Business
- Basic Research
- Intellectual Property Protection

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Ahead
1995, Current Trend:	Lead Rapidly Diminishing
1995, Best Case:	Ahead

VISUALIZATION

DEFINITION: Efficient presentation of complex data to humans increasing requires graphical representation. Graphics and visualization technology consists of the software and hardware that permits effortless generation of fast, high quality graphic images from data.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Applied Research and Development
- Intellectual Property Protection
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Quality
- Collaboration among Academia, Government and Business
- Basic Research
- Standardization and Standards

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently: Ahead

1995, Current Trend: Lead Rapidly Diminishing

1995, Best Case: Ahead

DISPLAYS

DEFINITION: Displays play and increasingly important role in the capabilities of terminals, work stations, personal computers, and portable computers. Display technology includes flat panel displays, cathode-ray tubes and related technologies that emphasize cost-effective increases in screen size, resolution, and image quality. Technologies include liquid crystal, electroluminescent, plasma and vacuum fluorescent display techniques.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Critical Mass
- State of Art Manufacturing
- Quality
- Applied Research and Development
- Research, Development and Manufacturing Linkages
- Skilled Personnel

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Large Market Siz[illegible]
- Private Sector C[illegible]ration
- Collaboration among Academia, Government and Business
- Basic Research
- Culture Issues
- Reduced Risk for Large Emerging Market

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Behind
1995, Current Trend:	Losing
1995, Best Case:	Lead Rapidly Diminishing

HARDCOPY TECHNOLOGIES

DEFINITION: Paper documents (hardcopies) continue to be important means of getting information onto and out of computer systems. Hardcopy input and output technology includes scanners, electrophotography, ink jet, thermal electrostatic, magnetography, ion deposition, wire matrix impact and full character impact printers.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- Large Market Size
- State of Art Manufacturing
- Quality
- Applied Research and Development

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Critical Mass
- Basic Research
- Intellectual Property Protection
- Culture Issues
- Reduced Risk for Large Emerging Market
- Research, Development and Manufacturing Linkages
- Skilled Personnel

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Behind
1995, Current Trend:	Behind
1995, Best Case:	Lead Rapidly Diminishing

OPTOELECTRONICS

DEFINITION: Optoelectronic components are revolutionizing the way data is moved quickly and reliably among the elements of a computer system or around a network of computer systems. The optoelectronic industry includes electronics for multiplexing and encoding data and for data recovery and de-multiplexing, as well as photonics for optical emitters and drivers, fiber optics and optical receivers.

HIGH-IMPACT CRITICAL SUCCESS FACTORS:

- Capital Investment
- State of Art Manufacturing
- Quality
- Applied Research and Development
- Basic Research
- Research, Development and Manufacturing Linkages
- Skilled People

MEDIUM-IMPACT CRITICAL SUCCESS FACTORS:

- Critical Mass
- Large Market Size
- Private Sector Cooperation
- Collaboration among Academia, Government and Business
- Standardization and Standards
- Intellectual Property Protection
- Culture Issues
- Reduced Risk for Large Emerging Market

POSITION OF U.S. COMPUTER SYSTEMS INDUSTRY VS. THE REST OF THE WORLD:

Currently:	Lead Rapidly Diminishing
1995, Current Trend:	Lead Rapidly Diminishing
1995, Best Case:	Behind

III. FACTORS AFFECTING U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

Overview

The U.S computer systems industry was so dominant in the early 1980s that, to a large extent, some slippage from the high market shares was to be expected. In a competitive world economy, successful enterprises will always invite competition, both in the form of imitation and improvement. The challenges to U.S. market share have occurred at a time of rapid growth for the computer industry, so that despite their loss of market share, U.S. producers' sales of computer products continued to grow at a rapid rate during the past decade. The reasons for the changes in market share are complex, but can be grouped into four general factors:

- The impact of increased capital requirements in the industry;
- The differences in the business environment between the United States and other countries;
- The differences in government policy toward industry between the United States and other countries;
- Differences in industry structure between the United States and other countries.

These factors are discussed below.

Impact of Increased Capital Needs

The cost of innovation has risen dramatically. R&D spending by U.S. electronics companies rose from 3.7% of sales in 1977 to 7.9% of sales in 1987. The more than doubling of the rate of spending on R&D reflected the shortening of product life cycles and the resultant need for new product and process introductions. Between 1976 and 1985, R&D spending by U.S. semiconductor companies rose from $227.8 million to $1.6 billion, while similar spending in the same period by Japanese semiconductor firms increased from $164.7 million to $1.3 billion[9].

Beyond R&D investment, capital spending for plants and facilities required to remain competitive has also escalated. When Intel began manufacturing semiconductors in 1968, it did so with an initial investment of $3 million[10]. In 1980, the cost of a typical state-of-the-art facility for semiconductor memory chips was $25 million. Today, building and equipping a modern semiconductor plant costs between $200 million and $300 million. A fabrication facility for 4 megabit DRAMs, the next generation of memory chips, is expected to cost between $500 million and $1 billion.

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[9] cited in: Charles Ferguson, "From the People Who Brought You Voodoo Economics," Harvard Business Review, May-June, 1988, p.61

The nature of international competition also has changed. U.S. firms operate in a different macroeconomic environment than do their foreign competitors. Given the capital intensity of the industry, the cost of investment capital is an important determinant of the speed at which industry can respond to competitive challenges. Numerous studies have demonstrated the gap between Japanese and American capital costs over the last 20 years.

In addition, Japanese firms use proportionately more debt than do American firms. The combination of these two factors serves to substantially lower both the operating costs of Japanese firms relative to those of U.S. firms and the "hurdle rate" for investment decisions. This provides strong incentives for Japanese company leaders to undertake more product development and R&D expenditure than their U.S. counterparts and to accept longer pay-back periods on their investment.

Differences in Business Environment

Government Technology Development Investments

While all governments help fund computer systems R&D, most of the U.S. Government's funding is related to defense whereas most of Japan's efforts are on civilian products. In 1987, defense accounted for only 5% of government funded R&D in Japan, compared with 69% in the United States. As discussed later in this paper, such defense-dominated funding skews U.S. federal research priorities and dramatically reduces the commercial benefits of government research.

There is also a major difference in the focus of R&D efforts between U.S. and Japanese firms. Whereas U.S. firms tend to allocate most of their R&D dollars to developing new products, their Japanese competitors invest the bulk of their R&D dollars in process improvements. A recent study by Professor Edwin Mansfield of the University of Pennsylvania found that the average U.S. company spends 70% of its R&D budget on product development and only 30% on the manufacturing process. In the average Japanese firm, however, the percentages and priorities are reversed[11].

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[10] National Research Council, Keeping the U.S. Computer Industry Competitive, p. 61

[11] cited in Keeping the U.S. Computer Industry Competitive, p. 27

Education of Labor Force

In order to maintain its technological base in computer systems, the United States must have a well-educated scientific and engineering work force and a technically literate population. The education that U.S. worker receive -- especially in science and mathematics -- does not provide them with the skills required to deal with the advanced technology that permeates today's manufacturing process. Furthermore, a strong foundation in science and mathematics -- from elementary through post-graduate levels -- is required to ensure the research and development activities that are needed to advance computer-related and other technologies. While in the 1960's American students performed as well as students anywhere in the world, U.S. students today are generally near the bottom in international math and science competency comparisons. On the other hand, Japanese students have placed near the top in these tests. Furthermore, interest in technical careers is dropping among all types of U.S. students: for example, since 1982, interest in computer careers has fallen from nearly 9% of incoming college freshmen to less that 3%[12].

Government Policy Towards Industry

The role of Government in fostering high technology industries has also changed. Today, some foreign governments --especially the Japanese Government -- view the gaining of competitive advantages in key industrial segments in strategic terms. They thus facilitate the development of competence by individual firms through tax incentives, permissive antitrust laws and cooperative research and development programs. The U.S. Government, while supportive of the competitive concerns of the U.S. industry, is ambivalent about its proper role.

A case in point is the effect of U.S. antitrust laws on the competitiveness of U.S. industry. Movement towards a redefinition of the "market" that would go beyond that of the United States and would take into account the size of the international marketplace and the nature of international competition has been slow. While, as a result of the National Competitive Research Act of 1984 (NCRA), close to 200 private sector consortia have been formed to undertake collaborative R&D projects, anti-trust concerns such as treble damages still inhibit joint manufacturing consortia. With escalating capital costs in such sectors as semiconductor manufacturing, few U.S. firms can afford to make these investments on their own and extension of the NCRA to include joint manufacturing has been high on industry's agenda. Such an extension would permit strategic alliances between U.S. companies that would allow them to pool resources when engaging in high risk, capital intensive production ventures and to achieve production economies of scale realized by large, vertically integrated foreign competitors.

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[12] The Coalition for National Science Foundation, Investment for the Future (in draft), 1990

Government-Industry Cooperation in Research and Development

Both the Japanese Government and the EC Commission are playing important roles in fostering their computer systems industries.

By far, the closest involvement of any government has been in Japan. Since the late 1950's, the Japanese Government has viewed its computer industry in commercial and strategic terms and has carefully nurtured it. The Japanese Government played a critical role in the development of computer technology not only in providing research subsidies but in also identifying priority areas for R&D, establishing policies and programs and building a consensus among Japanese computer firms to work together to achieve significant R&D objectives in national projects[13]. The resultant joint research associations brought together government research institutions and Japanese computer manufacturers to give the industry an effective vehicle to undertake long term R&D that individual companies could not afford. The results of the R&D were shared by Japanese firms, which were and continue to be each other's fiercest competitors, and were transferred to their corporate laboratories for development into commercial products. According to the Commerce Department, these national research projects, which were guided by MITI in the 1970's, reduced costs and risks and played an important role in Japan's efforts to catch up with the United States. Notwithstanding the involvement of the Japanese Government in these research efforts, industry supplied 50% or more of the annual computer related R&D spending between 1970 and 1984 (with the exception of 1974). By 1984, industry's share had risen to 77% of total R&D spending.

The Japanese Government is currently supporting R&D programs that seek to help its computer industry gain technological superiority is the world market. For example, MITI's largest current effort is the 10 year - $357 million Institute for New Generation Computer Technology (Fifth Generation Computer Project). The project is aimed at parallel processing and artificial intelligence technology, although it has not yet produced a system that can be operated using human language. MITI plans to launch a sixth generation project, which is expected to rely on optical switches, operating in parallel, to eliminate the constraints of conventional computing. The Japanese Government is also promoting cooperative ventures directed at improving the competitiveness of the of Japanese industry in software and microprocessors. For example, the SIGMA project aims at increasing the productivity of Japanese software developers. The TRON Association, comprised of interested Japanese companies, is a private sector cooperative effort to with the academic community to "develop a brand new and open architecture based on VLSI technologies." The extent to which there is governmental involvement in the TRON project is unclear to the Commerce Department.

Other governmental policies have helped in developing the Japanese computer industry. For example, the Electronics Promotion Law of 1957 permitted exemptions for the industry from the Anti-Monopoly Law. General tax benefits, such as an R&D tax credit and accelerated depreciation schedules for R&D capital, were enacted to encourage industrial research, while special deductions for expenses related to foreign trade and investment were designed to stimulate exports. To expand the use of computers in Japan, industry specific measures, such as special depreciation schedules for on-line and large scale computers as well as reductions in local fixed asset taxes on mainframes, were enacted in the late 1960's. An extensive system of income tax deductions was provided to computer hardware manufacturers and software developers to raise their return on investment. The Japanese Government, principally through the Japan Development Bank and other quasi-public development banks, also provided low interest loans and loan guarantees to the industry.

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[13] Department of Commerce, The Competitive Status of the U.S. Electronics Sector p.79

Cooperative efforts in R&D are also under way in Europe. These cooperative efforts in joint research or joint ventures cross borders and seek to link together key national firms, universities, and research centers as well as small firms that are working in similar areas. As a general rule, these programs place an emphasis on precompetitive research.

Eureka (European Research Coordination Agency) was established in 1985 to close the technological gap between Europe and Japan and the United States. Eureka's membership includes 22 European countries and the EC. Since 1985 it has undertaken 302 joint R&D projects that are aimed at developing technologies in such areas as information and telecommunications, semiconductors, robotics, materials, and manufacturing.

Eureka has also been used to shore up Europe's semiconductor industry. JESSI (Joint European Sub-micron Silicon) is funded by Eureka ($4 billion over eight years) and seeks through joint research conducted by the main European producers to develop sub-micron and silicon process technology and the manufacturing and design capability to be competitive to world standards.

Under ESPRIT (European Strategic Program for Research and Development in Information Technologies), the EC and participating companies expect to spend $5 billion by 1993 to bolster Europe's competitiveness in advanced components and to develop technologies and tools for systems design and information technology integration. ESPRIT began in 1984 by funding a series of precompetitive efforts in microelectronics, software technology, advanced information processing, office systems, and computer-integrated manufacturing. It is currently in its second phase, which will focus on stimulating market-oriented investment and production, especially in high-density integrated circuits (ICs), high-speed ICs, and multifunctional ICs.

The U.S. computer industry benefitted greatly from U.S. Government support. Between 1949 and 1959, the U.S. Government--principally, the Department of Defense--was responsible for funding almost 60% of computer R&D[14]. The Government supported much of the work that led to subsequent refinements and innovations that made the first electronic computers into commercial products. DARPA funded the initial research in some of today's leading edge computing technologies--artificial intelligence, computer graphics, time sharing, and parallel processing. While most of the key fundamental advances in semiconductors, including transistors and integrated circuits, came out of private R&D, the Defense Department, by spending money on R&D, sent a signal to private sector investors that the military would be a large potential market for good semiconductor devices. Today, DARPA continues to fund much of the basic research in computer science and engineering.

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[14] Department of Commerce, The Competitive Status of the U.S. Electronics Sector, p. 144

In 1987 DARPA and 14 U.S. semiconductor producers jointly funded SEMATECH, an R&D consortium devoted to the development of advanced semiconductor manufacturing technologies that would be transferred to member companies for commercialization. DARPA has invested $100 million in each of the first three years and it is understood that it will provide similar funding over the last two years of the project. DARPA was able to relate the funding of SEMATECH to its national security mandate, since the results of the R&D on basic process technologies would be directed toward military uses as well as to improving the competitiveness of the U.S. semiconductor industry.

Notwithstanding the continuing recognition of the linkage and importance of computer technology and components to U.S. security, changed conditions make commercial spinoffs from military-sponsored R&D less likely. Military R&D is becoming less relevant to the needs of the commercial market. Rather than focusing on generic technologies that will prove useful to both industry and the military, much of DARPA's funding is focused more narrowly on elaborate and sophisticated military applications of such technologies as artificial intelligence and parallel processing. Furthermore, commercial technology has out paced military state of the art, so that in a number of technologies, such as digital electronics, defense R&D offers little knowledge of commercial value.

Reductions in the defense budget and "national security needs" also can be expected to make future commercial spinoffs from military R&D less likely. The President's FY 1991 budget requested a 4% increase for defense R&D, which represents virtually no real growth. Furthermore, in times of shrinking research budgets, more of the remaining pie will go to major projects, such as the Strategic Defense Initiative, that have direct military payoffs and do not directly enhance the nation's commercial competitiveness.

Industry Structure

Part of the challenge to U.S. industry stems from the industrial structure of foreign competition. Vertical and horizontal integration, large size, and product diversity of Japanese--and to a certain extent, European--computer producers give them an advantage of staying power over their U.S. competitors. In Japan's case, this further leverages the its lower cost of capital. Because Japanese firms have captive suppliers of raw materials, semiconductors and other upstream and downstream products, they also realize cost advantages and supply source reliability that U.S. firms that produce for specific segments of the computer, and no other, market do not have. Moreover, because there is commoditization of many components (i.e., a consumer electronics product or a medical instrument may use a similar microprocessor or other component), the vertically and horizontally integrated Japanese firms can use skills gained in production of one end product on related high-end products.

Finally, the role of the individual firm has changed. As contrasted with U.S. industry, which is characterized by an entrepreneurial spirit, fierce individualism and aggressive competition, foreign--especially Japanese--firms recognized early on the need to cooperate among themselves in order to improve their competitive positions. For example, the six Japanese mainframe computer manufacturers, sixteen personal computer producers, and thirty-four semiconductor firms compete fiercely against one another. Nevertheless, they have also formed cooperative "alliances" to pursue certain research, production, and marketing goals that we in their mutual interest. This has permitted them to master the complexity, scale, and risk of ever-advancing computer-related technologies that increasingly demand more resources than even the largest individual firms can afford. The ability of Japanese companies to learn from other firms and develop capabilities across the broad spectrum of research development and marketing has permitted them to realize commercial benefits and increased market share.

A good example is the Japanese and U.S. approaches to developing x-ray lithography, which is an expensive technology that taxes the financial resources of even the largest firms in the industry. Japan has established nineteen cooperative projects to develop and implement x-ray lithography in semiconductor R&D and manufacturing. More than a dozen synchrotrons are under construction in Japan. In the United States, synchrotron-based x-ray lithography efforts are limited to the Brookhaven National Laboratory and a smaller initiative at the University of Wisconsin. IBM Corporation is building the only privately owned synchrotron in the United States.

IV. FACTORS IN MAINTAINING OR REGAINING U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

While the overall international competitiveness of the industry is dependent on a wide range of economic and social factors, a narrower group of factors is especially relevant to maintaining or regaining U.S. leadership in the nine technologies that were identified as critical to the U.S. computer systems industry.

The senior research officials of CSPP member companies were asked to evaluate the importance of each success factor for nine of the critical technologies. They followed an iterative process that combined quantitative measures based on an analytical weighting of the factors and qualitative judgments by the technologists and public policy specialists of the CSPP member companies regarding the importance of individual factors to specific technologies. The evaluations were tallied and are displayed, for the nine technologies, in Exhibit 8.

The grid facilitates a comparison of the nine critical technologies to the fifteen success factors and indicates the relative importance of each of the factors in helping maintain or regain the U.S. leadership in each of the technologies. Of the fifteen factors that were evaluated, six factors were judged to have a strong relationship, five were judged to have a medium relationship, and four were judged to have a weak relationship to U.S. leadership in each of the technologies.

The eleven factors that fell in the "strong" and "medium" categories are discussed below:

<ins>Capital Investment</ins> - Cost and availability of investment capital are important determinants of the speed at which the elements of the U.S. computer systems industry can respond to foreign competitive challenges. The availability of long-term resources necessary to build and sustain the infrastructure required to research, develop, and produce competitive products is especially needed to succeed in:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Networks and communications
- Manufacturing technology

<ins>Critical Mass</ins> - Ability to develop economies of scale in facilities needed to research, develop, and produce competitive products plays an important role in the competitiveness of the computer industry. The fragmentation of U.S. industry -- as opposed to the vertical and horizontal integration of its foreign competitors -- does not permit individual firms to gain the cost, skill, and product advantages reaped by their vertically and horizontally integrated foreign competitors. Technologies requiring a critical mass to succeed are closely correlated to those needing capital investment:

- Microelectronics

- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Manufacturing technology

Large Market Size - The sale of competitive products at a profit requires a significant market size. Ability to compete in markets is dependent not only on product quality but also on the presence of industries that create the demand for the critical technologies. Consumer electronics is such a technology driver. Loss of much of the U.S. consumer electronics industry, for example, has hampered the growth of the U.S. semiconductor and related industries and has made it difficult for U.S. computer companies to exploit the converging technology base. Large market size is a critical success factor for :

- Microelectronics
- Electronic packaging
- Storage (optical & magnetic)
- Manufacturing technology

Intellectual Property Protection - The worldwide system of laws protecting owners' proprietary interests in inventions, works of authorship, trademarks, trade secrets, and other forms of intellectual property provides the incentives needed to encourage the innovation and creativity that are critical for maintaining competitive positions. The rapid pace of technological change together with the desire, in some developing countries, to use intellectual property developed elsewhere, makes the development of predictable intellectual property regimes in the developed countries especially important. Intellectual property protection is a critical success factor across the broad range of technologies. It, however, is especially important in the creative technologies of:

- Microelectronics
- Applications technology

State of Art Manufacturing - Manufacturing competence is essential for competing in the high-volume markets that fuel revenue and technological growth. Manufacturing facilities that include the most advanced tools and technologies such as CAD, CIM, flexible manufacturing, and robotics would provide cost-effective, high quality, and responsive production processes for a wide range of fundamental, capital-intensive technologies:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Manufacturing technology

Applied Research and Development - Research and development efforts focused toward specific commercial applications is considered by the CSPP technologists to be the most important single success factor for the long-term competitiveness of the industry. Such commercially oriented research efforts can be undertaken individually by firms or on a collaborative basis with or without government involvement. European and Japanese governments are extensively involved in linking up their industry and governmental research structures in the area of applied R&D. Applied R&D is a success factor for all nine technologies:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Computer (processor) architecture
- Networks, communications
- Manufacturing technology
- Applications technology
- Software engineering

Basic Research - The exploration of fundamental phenomena not specifically related to direct product development generates the new ideas that set the stage for future technological and economic advances. Notwithstanding the overwhelming importance of continued applied R&D efforts, basic research is a critical factor for the fundamental and capital intensive technologies:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Computer (processor) architecture

Linkages Between Research, Development, and Manufacturing - In rapidly changing markets, delays in quickly transforming discoveries into high-quality products and into processes for designing, manufacturing, marketing, and distributing competitive products can mean the difference between success and failure. The traditional model that viewed manufacturing as a linear process in which design and engineering as separate from production and marketing is no longer relevant. Concurrent involvement in the product development process by research, development, and manufacturing personnel, however, can lead to timely and cost effective commercialization and incremental product involvement. Such linkages are important factors in the fundamental, capital intensive technologies:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Manufacturing technology

Skilled Personnel - Commercialization of scientific and technological innovation in an interdependent and rapidly changing worldwide marketplace requires an educated and properly trained work force. Availability of such personnel at all levels is a critical success factor for all nine technologies:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Computer (processor) architecture
- Networks, communications
- Manufacturing technology
- Applications technology
- Software engineering

Quality - Quality and price are rapidly becoming more important in determining market success relative to R&D. Firms that are successful in large volume markets will be those with superior product design, quality, and reliability as well as with manufacturing efficiency. Excellence that pervades all aspects of research, development, manufacture, delivery, installation, and service will result in globally competitive products. This factor is especially critical for:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging
- Storage (optical & magnetic)
- Networks, communications
- Manufacturing technology
- Software engineering

Private Sector Cooperation - The global business environment in which advanced technology ventures must compete is fast paced, expensive, and demanding. The cost of research, development, and manufacturing of advanced technology products that generally have short lives can outstrip the capabilities and resources of most U.S. firms. Joint manufacturing as well as research activities among U.S. companies would reduce costs by permitting the pooling of resources, the sharing of technologies, the spreading of risks, and the combination of production. Private sector cooperation is especially needed to succeed in:

- Microelectronics
- Integrated circuit fabrication equipment & facilities
- Electronic packaging

V. IMPLICATIONS FOR PUBLIC POLICY

The identification of the eleven success factors has implications for the direction of certain public policies that, if improved, would strengthen those factors and hence lead to the advancement of nine technologies that are critical to the future competitiveness of the industry.

While the purpose of this sectoral study is to identify those technologies that are critical to the computer systems industry and not to make public policy recommendations, a public policy agenda that would be relevant to the specific technology needs to the computer systems industry suggests itself. Such a technology-driven agenda would focus on the following public policy issues areas:

- Cost of Capital/Tax Policy - Governmental efforts to reduce the cost of capital and increase its availability through, for example, the reduction of the federal budget deficit and tax policy changes designed to promote savings and encourage greater long-term investment in research and development and in plant and equipment.

- Education - Private and public sector efforts to focus attention on the implications for U.S. competitiveness of the current educational shortfalls and legislative proposals to provide incentives -- through tax policy and fellowships -- to proposals to encourage more education and training, particularly in mathematics and science.

- Federal Research, Development, and Manufacturing Priorities and Support for Industry and Academia - The current debate over the proper role of government in fostering "strategic industries" through, for example, greater federal coordination of science and technology policy: shift in government funding from research in dual use technologies to research in more commercially applicable technologies; greater support for cooperative applied research efforts; restructuring of the government infrastructure and shift in emphasis of government funding from "big" science to "small" science projects.

- Consumer Electronics - The current debate over the proper roles of the government and the private sector in recapturing a strategic industry that has increasingly com to be recognized as the key driver for future critical technologies.

- Legal Regimes - Current efforts to ensure that U.S. antitrust laws and worldwide and domestic intellectual property protection support -- and do not hinder -- the international competitiveness of U.S. industry.

EXHIBIT 1

COMPUTER SYSTEMS INDUSTRY TRENDS
(In Billions of Current Dollars)

Year	GNP	Total U.S. Manufacturing Shipments	Wordwide Computer Systems Shipments of U.S. Companies
1977	1,990.5	1,391.9	40.3
1978	2,249.7	1,522.9	47.9
1979	2,508.2	1,727.2	54.4
1980	2,732.0	1,852.7	63.6
1981	3,052.6	2,017.5	71.3
1982	3,166.0	1,960.2	79.6
1983	3,405.7	2,054.9	91.4
1984	3,772.2	2,254.4	106.0
1985	4,014.9	2,280.2	116.6
1986	4,240.3	2,260.2	124.2
1987	4,526.7	2,390.0	139.3
1988	4,888.6	2,611.6	152.1
1989	5,234.0	2,781.6	163.8
Growth Rate*			
1979-1989	7.6%	4.9%	11.7%

---

* Average annual compounded rate

Source: U.S. Department of Commerce, CBEMA, and Datamation magazine, July, 1989.

EXHIBIT 2

FIRMS AND ESTABLISHMENTS COMPRISING THE COMPUTER SYSTEMS INDUSTRY*
1987

	Computer Equipment	Computer Storage Devices	Computer Terminals	Computer Peripherals	Software	Total
No. of Firms	938.0	100.0	122.0	520.0	19,167.0	20,847.0
Number of Establishments	974.0	106.0	121.0	549.0	21,594.0	23,344.0
Employment (000)	51.9	43.3	15.0	76.2	306.2	492.6
Value of Shipments ($ billion)	33.6	6.3	1.8	14.0	27.1	82.1

* Computers maintenance and related services, n.e.c., which accounted for $10.5 billion in shipments, 9,574 establishments and 96.8 thousand employees are not included in the above.

Source: "1987 Census of Manufactures" and "1987 Census of Service Industries."

EXHIBIT 3

COMPARISON OF U.S. COMPUTER SYSTEMS AND OTHER INDUSTRIES

	Electronics Sector				
	Computer Systems*	Electronics: Mfg & Software	Electronics & Related Services	Transp. Equip.	Chem. & Allied Products
Shipments ($ Billion)	97	208	433	373	255
Employment (000's)	587	2,000	2,600	2,053	1,093

---

* Worldwide shipments of U.S. companies were $164 billion and worldwide employment is estimated to have been 1.2 million in 1989.

Source: U.S. Census Bureau, Datamation and U.S. Department of Commerce (The Competitiveness of the U.S. Electronics Sector)

EXHIBIT 4

U.S. SHARE OF WORLDWIDE ELECTRONICS MARKETS
(1984 and 1987)

	Percent		Worldwide Market
	1984	1987	($B)
Silicon Wafers	85	22	$ >.01
Automatic Test Equipment	75	68	1.2
Semiconductor Mfg. Equip.	62	57	6.5
Microlithography Equip.	47	35	2.0
All Semiconductors	54	41	$38.1
ASICs	60	50	7.3
DRAMs	20	8	3.4
Microprocessors	63	47	1.7
Computers	78	69	$121.0
Personal Computers	75	64	47.2
Laptop Computers	85	57	1.6
Supercomputers	96	77	1.1
Computer Subsystems			
Displays	11	8	8.2
Flat Panel Displays	25	15	2.4
Floppy Drives	35	2	2.5
Hard Drives (up to 300 MB)	73	65	8.2
Hard Drives (up to 40 MB)	70	60	2.3
Dot Matrix Printers	10	8	4.8
Software	70	72	$44.5
Operating Systems	90	90	16.4
Data Base Mgmt. Systems	100	95	2.8
Spreadsheets	100	100	0.9
Telecommunications Equipment	33	32	$88.0
Central Office Switching	30	24	4.8
Fiber Optics	75	50	3.0
Private Branch Exchange	29	26	7.8
Data PBXs	100	36	0.2
Facsimile	30	25	3.1
Key Telephone Systems	28	22	5.7
Voice Mail Systems	100	100	0.6
LANs	100	98	2.4
Data Modems	49	37	3.2
Statistical Multiplexors	94	35	0.5
Instruments	52	46	$48.9
Medical Equipment	35	41	12.3
Photocopiers	40	36	13.4
Consumer Electronics	19	12	37.2

Source: Science & Electronics, U.S. Department of Commerce

EXHIBIT 5

PRICE INDEXES

Year	Consumer Price Index	Producer Price Index	Micro-Processors	General Purpose Computers
1981	100.0	100.0	100.0	
1982	106.1	104.0	96.8	
1983	109.5	105.7	93.1	
1984	114.2	107.9	97.6	
1985	118.3	108.9	86.6	
1986	120.6	107.4	83.4	
1987	125.0	109.7	77.8	
1988	130.1	112.4	73.1	100.0 (1)
1989	135.9	118.0	77.3	89.8 (2)
Growth Rate (3)				
1981-89	4.6%	2.9%	(3.2%)	
1988-89	4.4%	5.0%	5.3%	(10.2%)

---

(1) October, 1988 (This series was not compiled before 1988)

(2) October, 1989

(3) Average annual compounded rate

EXHIBIT 6

U.S. REPORT CARD: TRENDS IN EMERGING TECHNOLOGIES

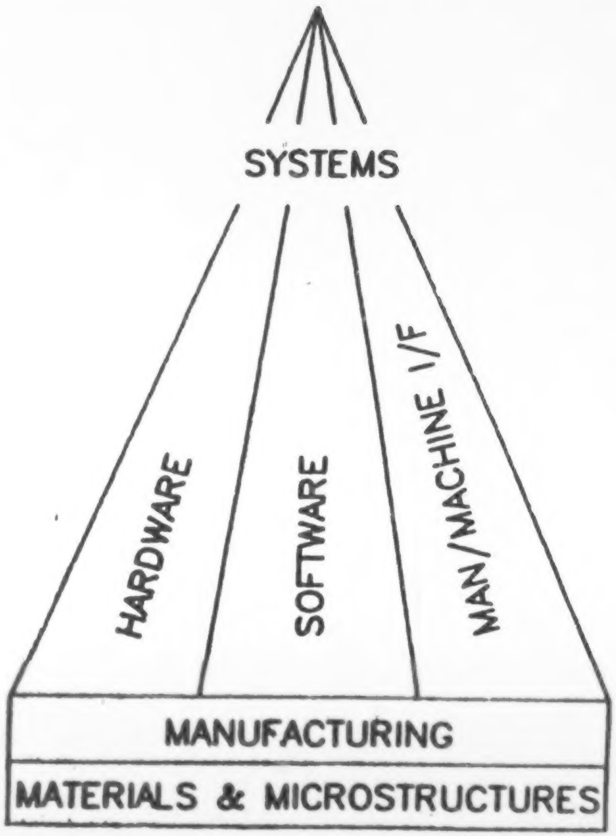
	Versus Japan	Versus Europe
Losing Badly	Advanced Materials Digital Imaging Technology Superconductors	Digital Imaging Technology Flexible Computer - Integrated Manufacturing
Losing	Advanced Semiconductor Devices High-Performance Computing Optoelectronics	
Holding	Artificial Intelligence Flexible Computer - Integrated Manufacturing	Advanced Materials Advanced Semiconductor Devices High-Density Data Storage Optoelectronics Superconductors
Gaining		Artificial Intelligence High-Performance Computing

Source: Department of Commerce, Emerging Technologies: A Survey of Technical and Economic Opportunities, Spring 1990

EXHIBIT 7

CRITICAL TECHNOLOGIES

- MATERIALS AND MICROSTRUCTURES
  - IC FAB EQUIPMENT
  - MICROELECTRONICS
  - OPTOELECTRONICS
  - PACKAGING
- MANUFACTURING
- HARDWARE
  - DISPLAYS
  - HARDCOPY
  - STORAGE (OPTICAL AND MAG)
- SOFTWARE
  - OPERATING SYSTEMS
  - SOFTWARE ENGINEERING
  - APPLICATION TECHNOLOGY
- MAN/MACHINE INTERFACE
  - HUMAN I/F
  - VISUALIZATION
- SYSTEMS
  - PROCESSOR ARCHITECTURES
  - DATABASE SYSTEMS
  - NETWORK COMMUNICATIONS


SYSTEMS
HARDWARE
SOFTWARE
MAN/MACHINE I/F
MANUFACTURING
MATERIALS & MICROSTRUCTURES

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

The Council on Competitiveness would like to thank William G. Howard, consultant to the Council, and the Computer Systems Policy Project for their work in the preparation of this profile.

The Council would like to thank Pfizer Inc. and NMTBA/The Association for Manufacturing Technology for their assistance in publishing the profiles.

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*Dr. Spencer served on the Committee in his role as Vice President, Science and Technology, Xerox Corporation, prior to his appointment to Sematech.

ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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A COMPETITIVE PROFILE OF THE
CONSTRUCTION INDUSTRY

Research Paper for

GAINING NEW GROUND:
TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future*.

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling and $20 for *Gaining New Ground* plus $2.50 postage and handling.

CONSTRUCTION INDUSTRY

EXECUTIVE SUMMARY

Key Points

- Construction is a huge industry, accounting for approximately 8.3% of GNP and employing 6.8 million people.
- It is highly fragmented, with divisions between designers and builders, between builders of different types of facilities, and between contractors, subcontractors, and suppliers.
- It is often viewed in the United States as a service industry -- providing design and construction services -- but can also be considered a productive industry like manufacturing except that the final assembly occurs at a construction site.
- International trade in the construction industry is primarily in design and construction management services, and in construction-related materials and equipment.
- The construction market in which international design and construction firms compete is different from domestic construction markets. The international construction market is characterized by large and technically complex projects and is dominated by large companies. The domestic market also includes smaller companies and less technical projects. Although it is to a large extent isolated from international competition, the quality and productivity of this segment of industry is still of national concern because of its large role in the national economy.
- U.S. construction industry is highly competitive in the international construction services market, but its substantial post-World War II lead has recently declined. In 1980, U.S. construction firms captured 45% of all international construction contracts; by 1989 they captured only 28%.
- The construction industry, especially in the U.S. is a low research and development (R&D), low productivity growth industry. Most construction technology is developed outside the construction industry, by materials and equipment manufacturers, and in universities and government laboratories. U.S. construction contractors spend only about 0.02% of sales on R&D; when materials and equipment suppliers are included, industry R&D represents about 0.4% of sales. There is, however, a significant opportunity to benefit from advanced technologies.
- The U.S. construction industry still has a strong position in many construction technologies, but its lead has eroded and it now lags behind in some areas of technology.

Critical Technologies

- Computers and Software
    - CADD/CAE/CIM
    - Databases

  - Expert or Knowledge/Object-Based Systems
  - Simulation
  - Planning/Scheduling/Inventory Management Systems

- Sensors

- Prefabrication and Modularization

- Advanced Construction Equipment

- Engineering Design and Analysis

- Advanced Construction Materials
  - Concretes, Composites, Steels, Plastics, Ceramics, Textiles, Glasses.

- Special Construction Technologies
  - Smart Buildings, Clean Rooms, Tunneling, Energy Systems, etc.

Threats to U.S. Leadership in Critical Technologies

- Low Industry Investment in Construction Industry R&D

- Barriers to Commercializing Construction Technologies
  - Industry Fragmentation
  - Lack of R&D and Testing
  - Building Code Process
  - Product Liability

- Growing Weaknesses in Related Industries that Drive Construction Technologies

- Potential Shortages of Engineers and Technically Skilled Workers

- Procurement Based on Cost Rather Than Quality

Factors Supporting U.S. Leadership in Critical Technologies

- An Open and Competitive Market

- Historical Strengths in Industries that Purchase Advanced Constructed Facilities

- Historical Strengths in Industries that Supply Construction Technologies

- Traditionally Strong Engineering Universities

- Innovative Industry that is Open to Ideas

I. INDUSTRY CHARACTERISTICS

The construction industry is usually considered to consist of the firms providing **design services** (both architectural and engineering) and **construction services**. Closely related to the construction industry are the industries that provide construction **materials, products**, and **equipment**.

The industry is noteworthy for its size. The value of "new construction put in place" in 1989 was $418 billion, equal to 8.3 percent of GNP.(1) The industry has consistently represented 7-12 percent of GNP. The industry employs 5.3 million employees and 1.5 million self-employed proprietors and working partners.(2)

Another key characteristic of the industry is that it is a project-based industry. Most of its products -- buildings, roads, energy production facilities, factories, etc. -- are mostly custom designed and built **one-of-a-kind products**. This limits the opportunities to benefit from economies of scale. A unique team of contractors and subcontractors is usually pulled together for specific projects and then disbanded afterwards.

In the United States, the industry is usually considered to be a service industry, and thus the role of technology is usually seen to be in improving the service of designing and constructing. An alternative view of the industry is as a productive industry like manufacturing except that the final product assembly is done onsite instead of in a factory. When viewed in this way, the materials, components, and equipment used in construction become an integral part of the industry, and thus the technologies in these segments of the industry become critical technologies.

Although the U.S. construction industry has been a **low productivity growth** industry, it is probably still the most productive construction industry in the world, at least in terms of being able to erect buildings quickly and efficiently.

Another key characteristic of the industry is that it is **highly cyclical**. It is very sensitive to interest rates, and its health depends upon the general condition of the economy and the status of individual industries and individual regions of the country. In addition, it is somewhat seasonal, particularly in the colder parts of the country.

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1. U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook -- 1990, Washington, U.S. Govt. Print. Off., 1990, p. 5-2. This figure includes renovations and home improvements, but does not include maintenance or repairs to existing structures. It includes the cost of building systems and appliances that are in the building at sale but does not include the price of the land.

2. Ibid.

Industry Structure

The industry is **highly fragmented**. One way in which it is divided is according to the **type of product**:

Private Construction $329 billion				
Residential	Industrial	Office Buildings	Other	Utilities
$198 bil	$14.9 bil (3)	$28.0 bil	$56.1 bil	$29.4 bil

Public Construction $80.9 billion			
Buildings	Highways & Streets	Water and Sewer	Other
$27.4 bil	$28.5 bil	$12.0 bil	$13.0 bil

Values are for 1988. Source: U.S. Department of Commerce. Construction Review, January/February 1990. Statistical Series.

Each of these segments of the market has somewhat different characteristics, and many contractors specialize in one or a few segments. The residential market, almost half of which is additions and renovations, consists mostly of small firms that do not compete internationally. There is, however, a small amount of international trade in prefabricated housing. The industrial and utilities segment consists mainly of large companies, often with several billion dollars in contracts each year. Many of these companies compete in the international market.

Many of the companies that work in the public works sector specialize in that sector because of the different marketing and bidding skills needed to win these contracts.[4] Unlike much private sector procurement, in which performance matters more than cost, in much governmental construction procurement, cost is more important than quality or performance. In addition, most government work is either engineering or construction, with few integrated engineering/construction projects.

The industry is also divided according to the **stage of product** development, with many different firms involved in different stages of the life of a given project. Typically an architectural and/or engineering firm designs a structure, a construction contractor manages the construction and receives competitive bids from many specialty subcontractors. Maintenance, repair, renovation, and demolition are also typically handled by separate companies.

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3. Industrial construction does not include construction that companies do themselves, which may be an additional several billion dollars.

4. National Research Council, Building for Tomorrow: Global Enterprise and the U.S. Construction Industry, Washington, National Academy Press, 1988, p. 30.

Upstream Industries

The construction industry is linked to several closely related industries. Many industries provide the materials and devices that go into constructed facilities, and the equipment to make them. These include:

```
+-------------------------------------+
|BASIC MATERIALS INDUSTRIES           |
|Wood and Wood Products               |
|Steel and other metals               |
|Stone, clay, cement, etc.            |
|Chemicals, plastics, adhesives, etc. |
+-------------------------------------+
                 |           +------------------------+
                 |           |  CONSTRUCTION EQUIPMENT|
                 |           |  Cranes, earthmoving   |
                 |           |       equipment, etc.  |
                 V           +------------------------+
+---------------------------------------------+   |
|CONSTRUCTION MATERIALS AND SYSTEMS INDUSTRIES |  |
|Brick, concrete, asphalt, drywall, glass     |   |
|windows, steel, paint, flooring, carpet,     |   |
|tile, piping, plumbing, electric wire,       |   |
|lighting, heating, cooling, and refrigeration |  |
|pumps, compressors, pressure vessels,        |   |
|elevators, etc.                              |   |
+---------------------------------------------+   |
                    |                              |
                    |                              |
                    V                              V
                  +-----------------------------------------+
                  |          CONSTRUCTION INDUSTRY          |
                  +-----------------------------------------+
```

The industries that contribute to the construction industry are quite diverse, ranging from basic materials to consumer durables to heavy equipment. Technology in development in these industries accounts for much of the advances in construction technology. Most suppliers to the construction industry are not to R&D-intensive industries. Low cost rather than high performance is the key criteria in many construction technologies. Because the construction market is cyclical, these industries also tend to have pronounced business cycles. U.S. constructors tend to have weak relationships with their suppliers and usually do not cooperate in technology development.

Downstream Industries

Downstream from the construction industry is the real estate industry and every industry that uses constructed facilities. For some industries, specialized and highly technical facilities, such as clean rooms for semiconductor manufacturing and containment facilities for nuclear power plants, are critical to the success of the industry. For most industries, the quality and cost of constructed facilities affect the industry's efficiency, but are largely taken for granted. Improved construction technologies can also help improve the public infrastructure, and economic studies have linked improved public infrastructure with improved productivity performance of the national economy.(5)

Another key impact is on energy consumption. Buildings and process facilities account for a large part of U.S. energy consumption, and construction technologies, such as energy conservation technologies and photovoltaics, can reduce this consumption. Through this means, building technology can indirectly affect the U.S. trade balance though its impact on energy imports.

Competitve Position of the U.S. Construction Indusrty

Trade in the construction industry is unusual because the final products -- constructed facilities -- are produced onsite. Design, engineering, and management services are exported, and construction materials, components, and equipment are also exported. Labor, except for supervisory personnel, is normally found in the project's country. These are discussed below.

International Design and Construction Market

Much of the international construction market is in projects that companies in the home country are not qualified to undertake, largely in developing countries or in the Middle East. These include large or technically demanding public works, industrial, or commercial projects. In addition, projects for multinational companies are more likely to be managed by international firms.

The U.S. construction industry is **quite competitive internationally, but** has been gradually **losing its post World war II dominance**. In 1980, U.S. **construction** firms captured 45 percent of all international construction contracts; by 1985 this percentage dropped to 35 percent and by 1989 it had dropped to 28 percent.(6) The current dollar value of foreign contracts going to U.S. firms also dropped, from around $50 billion in 1980 to $25.9 billion in 1988.(7) The U.S. construction industry still captures the largest percentage of the international market and its foreign contracts still exceed the amount of U.S. contracts won by foreign construction companies. In 1988, when U.S. contractors were awarded foreign contracts worth $25.9 billion, foreign contractors were awarded U.S. contracts worth $12.7 billion.(8)

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5. Hornbeck, John F., Transportation Infrastructure and Economic Development, Washington, Congressional Research Service report 89-102E, February 10, 1989, 27 p.

6. U.S. Congress, Office of Technology Assessment, International Competition in Services: Banking, Building, Software, Knowhow..., Washington, U.S. Govt. Print. Off., 1987, p. 132. U.S. Department of Congress, International Trade Administration, U.S. Industrial Outlook -- 1990. p. 514. Both sources use data from MacGraw Hill's Engineering News-Record.

7. U.S. Congress, Office of Technology Assessment, International Competition in Services: Banking, Building, Software, Knowhow..., p. 129, and U.S. Department of Congress, International Trade Administration, U.S. Industrial Outlook -- 1990. p. 514.

8. U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook -- 1990, Washington, U.S. Govt. Print. Off., 1990, p. 5-14. Data from Engineering News Record.

U.S. **design** firms (firms providing architectural and engineering services) also have the largest share of the world market (25 percent) and were awarded $1.0 billion in foreign contracts in 1988.(9) Foreign design firms were awarded $388 million in U.S. contracts. (These figures are for the work done by design firms, and do not include work done by engineering and construction firms.)

Only part of the value of foreign construction contracts won by U.S. companies returns to the United States. A 1983 survey of foreign contracts awarded to U.S. companies found that about a quarter of the value of the contract went to cover expenses incurred in the United States. The survey found that on average 11 percent went for salaries and fringe benefits of U.S. employees (excluding subcontractors), 10 percent went to the purchase of equipment and materials from other American firms, and 5 percent went to subcontracts to U.S. firms.(10)

The same is apparently true of foreign contracts awarded in the United States. Foreign contractors operating in the United States have not been profitable, which suggests that not too much money has been returning home.(11)

There are several reasons why the U.S. share of the international construction market has been declining. First, the **market has been shrinking**. Many mega-projects have been completed, the debt crisis in developing countries resulted in the scaling back or completion of many large construction projects, and the stabilization of oil prices has led to a slow down in construction in the middle east.

Second, there are **more players** in the market. Countries with extensive World War II damage finished rebuilding after the war and their construction companies moved to international markets to take up the slack. In addition, companies from industrializing countries, such as Korea and Taiwan, entered the international market and companies in many developing countries became competent to do an increasing amount of their own construction.

Third, the **U.S. lead in technology has eroded**. While the U.S. still has a strong position in many technologies, it no longer has the lead it once had, and lags behind in some areas of technology. The U.S. construction industry still has a strong position in areas of technology where U.S. industries are strong, such as building chemical plants, but other countries have advantages in areas where their natural environment has led them to develop a special expertise. For example, mountainous countries such as Japan, Austria, and Switzerland have become leaders in tunneling and bridge building.

Fourth, some other countries have foreign aid programs and other **export programs** that promote the interests of their construction companies to a greater extent than do U.S.

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9. "Foreign Design Billings Drift Higher," Engineering News Record, August 10, 1989, p. 43.

10. U.S. Congress, Office of Technology Assessment, International Competition in Services, p. 128, citing a 1985 study by Price Waterhouse.

11. Information provided by the U.S. Department of Commerce.

policies.(12) In addition, construction companies from other countries can often compete by offering lower interest financial packages than can American companies.

Another factor has been **changing patterns of foreign investment**. When companies invest in foreign countries, they often create opportunities for construction contractors from their own country. When U.S. companies expanded worldwide after World War II, they brought U.S. construction companies with them. When the oil rich countries increased their control over their oil resources, they opened up their construction markets to competitive bidding from companies from many countries.(13) This caused the market share of U.S. contractors to go down. More recently, when Japanese companies have built manufacturing plants in the United States, they have brought in familiar Japanese construction companies.

Trade in Construction Materials and Equipment

Because much construction-related trade is in materials and equipment, it is useful to examine the trade in these areas.

Construction Materials. The United States has recently run a trade deficit in construction materials, but the figures have improved as the dollar has fallen from its mid-80s high. The United States imported $12 billion in building products in 1986 and exported $4.9 billion to other countries.(14) In 1989, the U.S. had a surplus in wood products of $800 million but ran a deficit in non-wood construction materials of $1.9 billion and a deficit of $500 million in lighting fixtures.(15).

Construction Equipment. The United States construction machinery industry (SIC 3531), which includes various kinds of cranes, earthmoving, and paving equipment, has historically been a strong exporter. In 1978, the value of its exports was $6.5 billion; by 1987 they had fallen to $2.5 billion. By 1989 exports had recovered to $4.4 billion, and the industry had a trade surplus of $1.5 billion.(16) In other categories of general industrial machinery that are related to constructed facilities, such as pumps (SIC 3561), compressors (3563), and air conditioning, refrigeration, and heating equipment, (SIC 3585), the U.S. also has been running small trade surpluses.

Relationship to National Defense

The Department of Defense and Department of Energy Defense Programs are among the largest funders of construction-related research and development and are major procurers of constructed facilities. In 1986, the National Research Council(NRC) estimated that DOD funded about $80 million in construction-related research and

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12. National Research Council, Building for Tomorrow, op. cit., p. 38-47.

13. Professor Fred Moavenzadeh, MIT, personal interview, April 11, 1990.

14. MacAuley, Patrick H. and Robert M. Shaw, "Worldwide Value of Construction and Trade in Building Products," Construction Review, January/February 1990, p. iii. These figures are based on U.N.. data.

15. U.S. Department of Commerce, U.S. Industrial Outlook--1990, chapters 6 and 7.

16. U.S. Department of Commerce, U.S. Industrial Outlook--1990, p. 22-2.

development, mostly in the Army Corps of Engineers and the Air Force.(17) The NRC also estimated that the Department of Energy (both civilian and defense programs) funded over $30 million in construction-related R&D. Defense-related procurement of constructed facilities in 1989 included about $2.9 billion in military facilities construction and 1.1 billion in Federal industrial (primarily DOE) construction.(18)

II. CRITICAL TECHNOLOGIES

Innovation Process in the Construction Industry

The construction industry has often been portrayed as a technologically backwards industry with **poor productivity** growth.(19) The industry, however, is not stagnant -- buildings and construction today use many technologies that were not available 20 years ago.

The construction industry generally sees itself as a service industry that buys off-the-shelf technology, and conducts little R&D of its own. Much technology advancement is through "innovation by invasion" -- new technologies come into the industry from the outside, rather than from R&D conducted inside the industry. Much of this is based on R&D funded by the construction materials and equipment producers. Other technologies comes from other industries, such as the electronics and computer industry. The Federal government funds some construction related research in universities through the National Science Foundation, and conducts research at the National Insitutue of Standards and Technology Center for Building and Fire Research. In addition, the Department of Energy has funded research into energy efficient building technologies.

A 1986 National Research Council study estimated that U.S. construction companies funded $54 million in research (equivalent to about 0.02 percent of sales), but valued the benefits to the construction industry from R&D conducted by other industries to be over $800 million.(20) (Construction industries in most other countries are also low-R&D industries, but, as will be discussed later, still conduct more R&D than does the U.S. industry.)

In addition to R&D, **technology also advances through project development work.** When a project poses special problems or opportunities, the designers and/or contractors, often working with the future owner or user of the facility, figure out innovative ways to solve the problem and then apply the new expertise to future projects. In a similar manner, contractors sometimes try out new materials, equipment, or methods. If they are

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17. National Research Council, Committee on Construction Productivity, Construction Productivity: Proposed Actions by the Federal Government to Promote Increase Efficiency in Construction, Washington, National Academy Press, 1986, p. 28.

18. U.S. Department of Commerce, U.S. Industrial Outlook--1990, p. 5-1.

19. National Research Council, Committee on Construction Productivity, Construction Productivity: Proposed Actions by the Federal Government to Promote Increase Efficiency in Construction, Washington, National Academy Press, 1986, p. 28.

20. National Research Council, Committee on Construction Productivity, Construction Productivity: Proposed Actions by the Federal Government to Promote Increased Efficiency in Construction, Washington, National Academy Press, 1986. p. 31-45.

successful, they will be used on other projects. The experience and know-how accumulated by companies is a significant source of competitive advantage. Over time, the methods, materials, and styles that work endure. Much construction technology is not protected by patents. New technologies are picked up, used, and improved upon by others.

The introduction of new technology into the industry is generally a conservative process. Contractors are reluctant to try new materials or processes because the risks of failure, such as a failure to meet deadlines or budgets, or liability for a faulty product, outweigh the rewards of success. New technologies must also meet the complex and diverse **building codes** found around the country, which are intended to protect the safety of buildings, and these can prevent the economical use of some new technologies.

Critical Technologies

Critical technologies for the construction industry include information technologies, materials, equipment and process technologies, and product technologies.(21) These are described on the following pages.

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21. The information on these technologies comes from several sources, including Halpin, Daniel W., "Technology in Architecture, Engineering, and Construction," Contractor Report to the Office of Technology Assessment, February 28, 1986., and personal communication with Fred Moavenzadeh of MIT, Richard Wright of the National Institute of Standards and Technology, Richard Tucker of the Construction Industry Institute, John Fisher of Lehigh University, Charles Field of the National Association of Home Builders, and Bruce Vogelsinger, David Harris and Philip Schneider of the National Institute of Building Sciences.

CRITICAL TECHNOLOGY: Computers and software for Computer aided design, drafting, engineering, and various aspects of project management (CADD, CAE).

DESCRIPTION: Computer hardware and software for designing structures, preparing architectural drawings, engineering analysis, simulating the construction process, planning and scheduling, and inventory control.

WHY IS IT A CRITICAL TECHNOLOGY? Computers and software can greatly improve the productivity of the construction process. They make it possible to make more iterations of designs, to show clients what the facility will look like, and to identify construction problems at an early stage. Tying computer-based design to databases and computer-based project management systems can improve cost estimates, scheduling, inventory management, and can be used to coordinate the manufacture of prefabricated components with construction.

U.S. POSITION RELATIVE TO RoW:

Software = S
Hardware = H

	Lag	Par	Lead
1990		H	S
2000		HS	

Japan and Germany are closing fast

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:

The U.S. currently has an advantage because of the strong U.S. computer and software industries. Other countries are catching up in construction-related software.

The lack of standards and technologies for the automated exchange of data prevents easy communication between different companies and different parts of the industry. The lack of vertical integration in the industry also inhibits the exploitation of the full benefits of computer integrated design and manufacturing.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Depends on a robust software industry, adequate numbers of software engineers, and adequate engineers in construction-related fields who are competent with computers.

POLICY ISSUES:
Standard setting for exchange of information between CADD/CAE systems.
Intellectual property protection.
Engineering education.

CRITICAL TECHNOLOGY: Remote sensing and measurement technologies.

DESCRIPTION: Advanced technologies to help acquire construction related data. Includes non-destructive testing methods, and various sensors to assess condition of structures and environmental conditions within buildings. Also includes advanced surveying technologies, etc.

WHY IS IT A CRITICAL TECHNOLOGY? Sensing technologies can provide information that can improve decision-making about maintenance and repairs to the aging stock of buildings and infrastructure. Measurement and positioning technologies can greatly improve productivity in surveying and other measurement-related construction activities. Improved sensors are also important for improved automated construction equipment.

U.S. POSITION RELATIVE TO RoW:

Japan = J
Europe = E

	Lag	Par	Lead
1990		J,E	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
Lack of construction industry R&D. Lack of institutions that will demonstrate and test new technology developed in other fields.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Survey technologies benefit from the Global Position Satellites funded by DOD. Greater spinoffs from Federal research on sensors may be possible.

POLICY ISSUES: Technology transfer from federal research; Role of Federal and state agencies in using advanced technology public work infrastructure maintenance and repair.

CRITICAL TECHNOLOGY: Databases and Expert Systems

DESCRIPTION: Computerized databases on various types of construction information, including specifications and prices of materials, performance data on materials and structures. Includes knowledge-based expert systems to help make construction decisions.

WHY IS IT A CRITICAL TECHNOLOGY? Databases and object-oriented databases help construction companies to acquire, store, manage, and access the information and knowledge they need to build facilities. They aid in purchasing, inventory, accounting, quality control, scheduling, document control, cost control, and in meeting applicable standards. Databases and knowledge-based systems can aid decision-making and help store and transfer expertise within a company.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000		X	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Lack of vertical integration and standardization may prevent constructive sharing of information. Foreign efforts to catch up in expert systems and databases.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Related to computer, software, and communications technologies.

POLICY ISSUES: Standards for databases and expert systems.

CRITICAL TECHNOLOGY: Engineering Design

DESCRIPTION: Capability to engineer complex facilities, such as design of high-rises, construction engineering of tunnels and bridges; earthquake resistant design, design of buildings' mechanical systems, etc.

WHY IS IT A CRITICAL TECHNOLOGY? Enables engineers to optimize designs for large complex structures to achieve desired levels of performance and safety at minimum cost. State of the art capabilities in engineering design are necessary to compete in international design market. Engineering feasibility studies often lead to awards to construct international projects.

U.S. POSITION RELATIVE TO RoW:

U.S. position depends on type of construction; U.S. leads in high-rises but lags in design for bridges and tunneling.

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: The division between design and construction in the United States can lead to U.S. designs being less constructable than others. Shortages of engineers may lead to weaknesses in engineering design capabilities. Lack of institutions to test new design and liability problems prevent experimentation with new designs.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: CADD and CAE capabilities, computer, software, databases, expert systems.

POLICY ISSUES: Federal funding of basic engineering research and experimental equipment; research support for graduate students; science and engineering education issues; certification of codes for engineering analysis.

CRITICAL TECHNOLOGY: Automated Construction Equipment

DESCRIPTION: Increasingly computerized construction equipment to increase productivity of construction workers.

WHY IS IT A CRITICAL TECHNOLOGY? Robotics, "smart tools", and automated construction equipment can improve human productivity and can help compensate for an aging construction workforce and an expected shortages of workers. They can also reduce occupational injuries and reduce human exposure to highly hazardous workplace conditions (such as in hazardous waste cleanup and nuclear power plant maintenance).

U.S. POSITION RELATIVE TO RoW:

So far, there have been few successful construction robots. Japan has experimented the most. European companies are ahead in computer-controlled cranes.

	Lag	Par	Lead
1990	R		
2000	R		

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
Lack of domestic construction R&D. Relatively weak domestic automated equipment manufacturers. Difficulties in applying robotics to construction. Low capital intensity of industry. Lack of market demand.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Control, sensing, and information interface technologies are important related technologies.

Development of automated construction equipment depends on interaction of the construction industry with U.S. equipment manufacturers.

POLICY ISSUES:
Federally funded hazardous waste clean-up R&D could be used to develop robotics useful to the construction industry. Federal funding of robotics is mostly for the space program.

CRITICAL TECHNOLOGY: Prefabrication and Modularization

DESCRIPTION: Offsite fabrication of modules and components, and on-site prefabrication.

WHY IS IT A CRITICAL TECHNOLOGY? Uses economies of scale and standardization to improve productivity and control quality to levels difficult to achieve with field construction. It can also speed construction time.

U.S. POSITION RELATIVE TO RoW:

Lags behind Japan and Europe in some aspects of modularized construction, but are ahead in other aspects.

	Lag	Par	Lead
1990		X	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: The lack of integration of the U.S. industry makes it more difficult to make modules that cross divisions in the industry. Offsite fabrication undermines traditional labor structure in the industry. Diverse and complicated building codes make achievement of economies of scale more difficult, but also serve as a barrier to imports.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Lighter construction materials aid in prefabrication because they are easier to put in place. The integration of offsite fabrication with computer aided design and manufacturing can lead to customized offsite fabrication.

POLICY ISSUES: Uniform national building codes would greatly facilitate prefabrication and modularization.

CRITICAL TECHNOLOGY: Advanced Construction Materials

DESCRIPTION: High-strength concrete, fiber reinforced concrete, roller compacted concrete, latex modified concrete, higher strength steels, composites, engineering plastics, ceramics, fiberglass cables, etc.

WHY IS IT A CRITICAL TECHNOLOGY? New materials can improve durability, make possible new types of structures, and reduce construction costs. The are also critical for many specialized applications, such as hazardous waste containment

U.S. POSITION RELATIVE TO RoW:

Concrete = Cn
Roller Compacted Concrete = RCC
Composites = Cm
Steel = S

	Lag	Par	Lead
1990	Cn,Cm,S	RCC	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
U.S. advanced material research focuses on high cost applications rather than construction applications. There may be a lack of demand by the construction industry, in part due to a lack of research and testing capability. Product liability concerns also reduce demand for new materials. In addition, the building code approval process may delay use of new materials.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
These materials are largely developed outside the construction industry -- in the chemical, and building materials industries.
Construction poses a potentially huge market, especially if costs come down.

POLICY ISSUES: Improve testing/product approval/product liability system. Use of Federal procurement for constructed facilities to demonstrate and provide a demand for advanced construction materials. Technology transfer from Federal R&D in DOD, NSF, DOE, & NIST.

CRITICAL TECHNOLOGY: Specialized Building and Construction Technologies

DESCRIPTION: "Smart buildings", clean rooms; biotechnology research labs; power plants, etc.

WHY IS IT A CRITICAL TECHNOLOGY? These are types of buildings that require some specialized and often proprietary knowledge to build. Much international competition is in constructing these facilities that incorporate advanced technologies.

U.S. POSITION RELATIVE TO RoW:

clean rooms = C
smart buildings = S
flexible factories = F

	Lag	Par	Lead
1990	SC	F	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Loss of a competitive edge in the industries for which these facilities are built could cause loss of competitiveness in the related construction technologies -- e.g. loss of competitiveness in semiconductor manufacture could result in a loss of a lead in clean room technology; loss of a lead in nuclear technologies could lead to loss of a lead in constructing nuclear plants. For smart buildings, lack of standards may be a problem.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Interdependent with industries for which facilities would be built, and that produce specialized building components, including telecommunications, computers and software, consumer electronics, biotechnology, etc. Modularization is important in building many of these types of facilities.

POLICY ISSUES: Policies that affect capital investment in industries that need specialized facilities. Encouragement of R&D joint ventures between construction companies and facility owners (such as the Construction Industry Institute).

III. THREATS TO U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

Low Industry Investment in Research and Development

The main threat to the U.S. leadership in the critical technologies is that the United States invests relatively little in the research, development, and testing of new construction technologies. As noted earlier, the U.S. construction industry spends little on R&D -- contractors spend about of .02 percent of sales on R&D.(22) Construction companies in Japan spend over 0.5 percent of sales on R&D,(23) or roughly 25 times as much as their U.S. counterparts. Large Japanese construction companies have their own research centers, with advanced experimental equipment. Construction companies in Europe generally spend less on R&D than do Japanese companies, but more than American companies.

When U.S. construction-related R&D by equipment and material suppliers and government agencies is added to that funded by construction contractors, the total amount of construction R&D is around 0.4 percent of sales, which is still less than the amount spent by Japanese construction companies alone.(24) Japanese government and material and equipment suppliers spend a similar amount on R&D as do their U.S. counterparts, so the total level of construction R&D is considerably higher in Japan than in the United States.(25) More importantly, because much of Japan's construction R&D is done within the construction industry instead of outside it, the results of the research are more readily used.

There are many reasons why U.S. construction companies tend to fund less R&D than those in other countries. The cyclical nature of the industry and the low profit margins cause U.S. construction companies to refrain from investing in research engineers or experimental facilities that they might not be able to support in hard times. The fragmented nature of the industry combined with strong internal competition reduces the ability of any one company to conduct, or capture the benefits of, R&D. In addition, because many construction process technologies are not patentable and cannot be hidden in open construction sites, it is difficult to capture the full benefits of R&D.

In Japan, many of these disincentives are weaker. A construction company's income is more predictable because the Ministry of Construction looks out for the interests of construction companies and construction companies cooperate with each other

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22. The National Research Council in 1986 estimated that R&D by construction companies amounted to $54 million in 1984 dollars, compared to a value of new construction of $314 billion in that year.

23. Statistics Bureau, Management and Coordination Agency, Japan, Report on the Survey of Research and Development, 1987, Tokyo, March 1988, p. 92-95. Part of the discrepancy may reflect accounting differences. U.S. contractors tend to bury R&D in project costs, so it can be written off rather than amortized. In Japan, R&D spending is a factor the Ministry of Construction looks at when determining who may bid and who is awarded large public works contracts, which provides an incentive to exaggerate R&D costs.

24. National Reseach Council, Construction Productivity, op. cit. p. 34-41.

25. Cheney, David W, testimony before the House Committee on Science and Technology, Subcommittee on Science, Research, and Technology. R&D in the Construction Industry, Washington, U.S. Govt. Print. Off. 1989, p. 53-64.

to cushion the boom and bust cycles for any company. The large companies tend to rotate as the lead contractor on large projects. Because income is more predictable, it is easier for Japanese companies than American companies to maintain the overhead of an R&D facility. Because all major Japanese construction companies fund R&D, and because foreign competition has been effectively excluded from the Japanese market, contractors do not risk being undercut by companies that are not funding research. Company R&D is encouraged by the Ministry of Construction, which considers it as a factor in deciding contract awards. In addition, because companies compete less on price, they may compete more on technology and strive to get an advantage by doing construction that other companies are not technically competent to do.

Other factors also contribute to the difference. With the lifetime employment system in large Japanese companies, they are less able to acquire expertise by hiring it, and better able to capture the benefits of company R&D. A weaker university research system means that the companies have to fund more R&D themselves. In addition higher costs of capital and greater pressure from shareholders for short-term returns on investments decrease the ability of U.S. companies to fund R&D relative to overseas competitors.

Barriers to Commercializing Construction Technology

There are also weaknesses in the way the U.S. construction industry makes use of new technologies. Part of this comes again from the lack of construction company R&D. In the United States, most construction-related research is performed in university and government laboratories, and often takes a long time to be adopted by construction companies. In Japan, much of the research is done by the companies that will be using it and there are fewer barriers to getting research results from the lab to the market. The National Research Council observed that a more innovative environment exists in most foreign firms (European as well as Japanese) because R&D has been integrated into overall operations.(26) This enables them to take advantage of new technologies developed outside of the industry more quickly. By contrast, project managers in the United States, who are compensated for on-time, in-cost projects are resistant to new technologies because they suggest risk.

Another reason is that the separation of design and construction common in the U.S. industry means that no one entity has responsibility for the entire building process. Contractors often have little incentive to innovate because they are constrained by the specifications in the design. Innovations by designers may be met with resistance from constructors. Isolation of the different segments of the industry makes it hard for them to work together. While this problem is not the case for projects in which the designer is the same as the builder, Federal procurement practice is to require separate bids for design and construction.

Another factor is the process of testing and ensuring the quality of construction innovations. New materials and structures must be durable and safe, and the consequences of poor building performance or structural failure are large. Testing is expensive and building owners are reluctant to buy untested technology, which creates a major barrier to gaining the acceptance of a new technology. In the U.S., compared to other countries, more research is based on computer modeling, and less is based on experimental data. In Japan, much of the construction industry's research is devoted to extensive product testing, and the research centers at the major companies have elaborate

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26. National Research Council, Building for Tomorrow, op. cit.

testing equipment. In addition, companies often test innovations in their own buildings first before selling them to clients.

In the U.S. system, the use of new technologies is controlled by the building codes, which stipulate minimum standards to protect the safety of building occupants, and by product liability, which provides an incentive for builders not to use technologies that have the potential for causing harm. In the absence of extensive testing, the building code approval process becomes slower, and the product liability system has a stronger role in providing a disincentive to unsafe products. However, it also provides a disincentive to innovate and the total system is not an efficient way for getting new technologies into the industry.

Growing Weakness in Related Industries

One of the reasons for the strengths of the U.S. construction industry has been that it has been able to profit from other strong U.S. industries. For example, the construction industry leads in the applications of computers to construction because the U.S. is strong in computers and software, and the U.S. leads in building petrochemical and nuclear plants because the U.S. has been a leader in those industries. If the U.S. falls behind in an increasing number of other industries, this source of advantage will disappear.

Potential Shortages of Engineers

In addition to the science and engineering education problems facing other industries, the construction industry has the added problem of being perceived as a low technology industry. As a result, related fields of engineering are often not attractive to the best engineering students. One of the benefits Japan derives from its aggressive construction research programs and ambitious futures planning (such as designs for lunar stations), may be to increase the prestige of the industry to help attract top engineering talent.(27)

IV. FACTORS SUPPORTING U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

An Open and Competitive Market

The United States has an open, competitive market, which encourages companies to constantly find ways to lower costs and improve their productivity. In other countries, construction industries are often less price-competitive, and thus do not have as strong incentives for lowering costs. Companies are on the lookout for construction practices developed elsewhere that can lower costs. On the other hand, U.S. procurement practices are often too much oriented towards lowest first costs and may not result in the lowest long-term costs.

In addition, there are few barriers to entry in the U.S. construction market. If a small company has a new idea, they can exploit it. This is not true to the same extent in other countries, such as Japan, where one needs a license to operate and one must be prequalified to bid on public works contracts. Foreign companies do find barriers to working in the U.S., such as difficulties in working with labor unions and suppliers.

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27. Professor Fred Moavenzadeh, personal interview, April 11, 1990.

A Strong Computer and Software Industry

The U.S. has a strong computer and software industry that is responsive to the needs of industries such as the construction industry.

A Traditioinally Strong University System

U.S. civil and other engineering departments are still world leaders, and lead in many of the modeling, analysis, and software skills that are critical to the industry's competitiveness. Foreign companies, however, are often able to benefit as much as U.S. companies from U.S. university research. For example, Shimizu Corporation has a five-person office across the street from MIT to help tap into the technologies there.

Historical Strengths in Leading Edge Industries

Because the U.S. has created and led many new industries, U.S. construction companies have gotten early experience in construction for these industries. This has been true with the petrochemical and nuclear industries. It is not clear the extent to which these trends will continue into the future. As the U.S. has been losing its lead in new technologies, such as semiconductor manufacturing, the construction industry loses its advantage in building related facilities, such as clean rooms.

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

This research paper was prepared by Council Senior Associate David W. Cheney. Harold Forsen of Bechtel provided valuable input.

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ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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A COMPETITIVE PROFILE OF THE
DRUGS AND PHARMACEUTICALS INDUSTRY

Research Paper for

GAINING NEW GROUND:
TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future.*

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling and $20 for *Gaining New Ground* plus $2.50 postage and handling.

COUNCIL ON COMPETITIVENESS
SECTORAL PROFILE: DRUGS AND PHARMACEUTICALS

SUMMARY

Key Points:

- The U.S. pharmaceutical industry has been highly successful. It is the largest in the world, is highly profitable, and is a major force in the world market. Sales to U.S. consumers constituted 20 percent of the world total in 1988, while sales by U.S. firms were approximately 30 percent. The U.S. pharmaceutical industry has historically maintained a trade surplus, but this surplus has declined and almost disappeared as the market has become increasingly global.

- There are two segments of the prescription pharmaceutical industry, which operate with notably different competitive strategies. Research-based companies, accounting for 70 percent of total sales, specialize in name-brand products. Success in this segment depends on having a sufficient stream of new drugs that offer therapeutic advantages over other drugs on the market. Due to these companies, the pharmaceutical industry has the highest ratio of R&D funding to sales of any major U.S. industry. Companies in the generic drug segment of the industry, on the other hand, sell unbranded products after the expiration of the pioneer product's patent. They compete by offering products at lower prices.

- The U.S. Food and Drug Administration (FDA) regulatory approval process for new drugs governs the drug development process. Before a new drug can be marketed, the drug's sponsor must demonstrate the drug's safety and efficacy and assure the maintenance of quality throughout the production process.

- Getting a new drug through this process and to market is risky, expensive, and time-consuming. On average, for each new drug approved by the FDA, drug companies screen 4,000-10,000 chemicals and test 5-10 drugs in human clinical trials. For products introduced in the early 1980s it took on average 12 years and $231 million (including indirect costs) to bring a new drug to market.

- Competition to develop the best product within a therapeutic area can be fierce. The development process is long and unpredictable. Even clinically successful outcomes may not be financially rewarding. Only a small proportion of new drugs reward the sellers with large profits. Achieving high profits on a few products is essential to funding the research that may lead to new therapies; most private pharmaceutical R&D is financed out of the company's retained earnings.

- Companies have a short period in which to try to recapture most of their investment in a drug. Of the normal 17-year patent life, more than half may pass before a drug passes all regulatory hurdles and meets FDA requirements and is marketed. The recent accelerated market entry by generic drugs after the pioneer product's patent expires results in the pioneer product's market being quickly and deeply eroded when the period of patent exclusivity expires. This reduces a drug's lifetime earnings, which curtails funds available for research and development and also makes a stream of new products even more important.

- The high cost and risk of drug development, and the need to market drugs globally to maximize their earnings, are encouraging worldwide alliances and the consolidation of companies to finance the development and worldwide marketing of drugs.

Critical Technologies for the Pharmaceutical Industry:

The pharmaceutical industry is a science-based industry and builds on both advances in basic research and incremental advances in drug discovery and development. Research in a wide range of biological, biomedical and chemical disciplines is vital to understanding how to create chemicals that will affect specific biological processes.

- The **research base** for drug discovery and development is by far the most important factor affecting innovation in the pharmaceutical industry. The research base includes various branches of human physiology and studies of diseases, molecular and cellular biology, understanding of the relationship between chemical structure and bioactivity, physical chemistry, synthetic organic chemistry, toxicology, and pharmacology.

- **Biotechnology**, including recombinant DNA, cell fusion, and bioprocessing techniques, which are used both as research tools and as means of producing drugs.

- **Scientific instruments, equipment, and associated techniques.**

- **Supercomputers and software** for molecular analysis, modeling, and graphics.

- **Databases and networks** to store, manage, analyze, and access research and clinical trial results.

- **Artificial intelligence** software to assist in interpreting experimental and clinical data.

- **Drug Delivery Techniques** to increase the convenience and effectiveness of drugs.

Critical Issues

- **Basic Research Funding** Continued strong federal and industry support for biomedical research is critical. The predominant share (over 85%) of the $7 billion spent by the U.S. government through the National Institutes of Health is for basic research, and private industry devotes 28 percent of the $7.3 billion it spends yearly on research to drug discovery research. The magnitude of this private and government commitment to basic research is a competitive plus for the industry.

- **Intellectual Property Protection** The pharmaceutical industry requires strong intellectual property protection in order to invest money in drug development. Strong U.S. intellectual property protection is a competitive plus. Stronger international intellectual property protection and greater certainty regarding intellectual property for biotechnology products and processes are needed.

- **Drug Pricing Policies** The relative lack of price controls on drugs in the United States compared to other developed countries has enhanced the competitiveness of the U.S. pharmaceutical industry by sustaining the income of research-based drugs and, consequently, the funds available for R&D. Federal budget constraints and various public policy initiatives, such as Medicaid rebate legislation and the policies favoring the increased use of generic drugs threaten this source of funding.

- **Science Education** Highly skilled researchers in the biological and chemical sciences are critical to the success of the pharmaceutical industry. Weaknesses in precollege science education and the low numbers of students pursuing advanced training in the sciences threaten to weaken the pool of researchers needed for the pharmaceutical industry. Imbalance between the limited pool of university researchers and extraordinary demands for applied and clinical research is threatening the training of new researchers.

- **University/Industry/Government Roles in Research** Traditional roles of these institutions in funding and conducting R&D and training researchers have blurred leading to some inefficiencies and duplication of effort. In addition, the new relationships had created concerns about conflict of interest. Unnecessary or cumbersome conflict of interest rules could significantly disrupt the relatively easy flow of information and technology among the NIH, universities and the private sector and thus reduce the cross-pollination and resultant productivity of the research establishment.

- **Cost of Capital** The relatively high cost of capital in the United States relative to competing countries increases the cost of drug development. The long development and regulatory approval time for drugs increases the impact of capital costs.

- **Controls on Research and on Use of Experimental Animals** Less restrictive regulation of biotechnology research and products compared to the European Community is a competitive advantage for the U.S. drug companies. More restrictive controls in the United States could eliminate that advantage. Increasing controls on research, including controls on the use of laboratory animals, threaten to increase the costs and reduce the effectiveness of research.

- **Regulatory Environment for Drugs** The U.S. Food and Drug Administration, while criticized by some as being too slow at approving drugs, has a generally good record for maintaining public confidence in the safety and efficacy of drugs. Greater resources to maintain an adequate technical staff to reduce the backlog of drug applications and to evaluate changes in science and technology would support the competitiveness of the U.S. industry.

- **Product Liability** Product liability is a disincentive for innovation in some areas, such as vaccines, contraceptives, and medical devices.

I. INDUSTRY CHARACTERISTICS

Basic Information on the Industry

Definition :	In the Standard Industrial Classification (SIC) system the "Drug Industry" is SIC 283.[1]
Value of Shipments:	$54.9 billion (1989).
World Market:	$150 billion (1989)
Employment:	178,700, of which 83,400 were production workers (1990).
Research:	$6.6 billion[2]; 12.0% of sales (1989).

Key Segments of the Industry

Key divisions of the industry are as follows:

Prescription drugs (70% of the market) versus **non-prescription** or "over the counter (OTC)" (30% of the market).[3] The prescription drug market is much larger and includes the more powerful, expensive, and innovative drugs. At the same time, the OTC market is growing as consumers are becoming more involved in health care decisions. Competition in the OTC market is primarily in reformulating and marketing well-established active ingredients.

Generic (about 30 percent of the prescription market)[4] versus **name-brand** or **proprietary** drugs (about 70 percent of the prescription market). Generics are non-proprietary drugs, generally manufactured after the patent has expired. Generic companies are not research based; competition is based on price and merchandising. The name-brand sector of the industry is responsible for nearly all of the R&D and new drugs. The role of generic drugs is growing, due to the expiration of patents on major drugs, easier approval following the passage of the Waxman-Hatch Act, and pressures to contain health care costs.

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[1] In this system the industry consists of: SIC 2833, Medicinals and Botanicals, $4.8 billion (e.g. uncompounded medicines); and SIC 2834, Pharmaceutical Preparations, $45.4 billion (preparations such as liquids, tablets, pills, capsules, lozenges, powders, ointments, jellies, salves, inhaler tubes, etc.); SIC 2835, Diagnostic Substances, $2.5 billion; SIC 2836, Biological Products excluding diagnostics (e.g. vaccines and antibodies), $2.1 billion. Pharmaceutical markets are divided at the 5-digit SIC level by the type of drug, (such as antibiotics, central nervous system drugs, cardiovascular, etc). U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook 1991, Washington, D.C., U.S. Government Printing Office. 1990. p. 45-1,2. The data on value of shipments and employment are from the same source.

[2] U.S. based R&D of Pharmaceutical Manufacturers Association members, who conduct the vast majority of pharmaceutical industry research.

[3] U.S. Department of Commerce, Bureau of the Census, "Pharmaceutical Preparations, Except Biologicals, 1987," Current Industrial Reports, Washington, U.S. Govt. Print. Off, November 1988. 11 p.

[4] U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook 1990, Washington, D.C., U.S. Government Printing Office. 1990. p. 50-3.

Size Distribution of Companies

The pharmaceutical industry is characterized by moderate concentration and medium-sized companies. The top four companies have about 25 percent of the U.S. market; the top twenty have around 70 percent.[5] Internationally, the largest companies each have around 3-5 percent of the world market and have sales of around $4-7 billion. In addition to these large companies, which sell a full line of products, many smaller companies sell drugs in narrow market niches. Generic drug manufacturers also tend to be much smaller than the research intensive companies; they do not have the financial resources to develop new drugs. The several hundred biotechnology companies that focus on research and do not market drugs are also smaller. They often were started by a few scientists trying to develop a few ideas into products, and it is extremely difficult for them to acquire the resources to develop and market a drug worldwide. At the other extreme, some pharmaceutical companies are subsidiaries of much larger chemical companies, such as Bayer, Monsanto, and Dupont. Because of the need for an increasingly large research and marketing base, the industry has in recent years seen several major mergers, such as Smith Kline with Beecham, and other forms of joint effort, such as co-marketing agreements.

Key Relationships with Other Industries

Upstream Relations

The key inputs to the industry are knowledge and highly trained personnel. The key sources of knowledge and skills are universities, research hospitals, medical school research centers, government research laboratories (the National Institutes of Health in particular), and biotechnology companies. The industry also requires scientific instruments, computers, and software for research, and process equipment to produce the substances. The chemical and agricultural industries provide the basic feedstocks for the industry.

The pharmaceutical industry shares the biotechnology research base with other industries, particularly agriculture, agricultural chemicals and waste management. There is an especially close association with agricultural industries in the areas of animal medicine, animal gene therapy, and bioproduction of naturally occurring proteins.

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[5] Bozdogan, Kirkor, "The Transformation of the US Chemical Industry", in The Working Papers of the MIT Commission on Industrial Productivity, Vol 1, Cambridge, MA, MIT Press, 1989. p. 92.

Downstream Relations

The key downstream relations are with pharmacies, health care providers and funders, and patients. Health care providers include doctors, hospitals, health maintenance organizations (HMOs), and governmental health care systems. Health care funders include insurance companies and industry and government funding agencies, such as the Health Care Financing Agency (HCFA) in the Department of Health and Human Services.

Health care quality and costs indirectly affect the competitiveness of other industries. Improved worker health contributes to competitiveness while higher health care costs hurt competitiveness. Although there are efforts to control health care costs by controlling drug prices, this is likely to be counterproductive in the long run. Drugs amount to only about 7% of health care costs, and reduced drug prices limit the industry's ability to develop new drugs that have the potential to replace more costly therapies. In most other industrialized countries, where total health care costs are lower, drugs represent a greater percentage of health care costs.[6] Indeed, whenever drugs replace more expensive forms of medical treatment, they reduce health care costs.

Relationship to National Defense

The Department of Defense (DOD) is relatively unimportant to the pharmaceutical industry, compared with other industries. DOD is the second largest federal funder of biotechnology research, but at around $120 million per year DOD funding is only 1/20th of that of the largest funder, the NIH.[7] Some DOD research is on vaccines that may be needed by DOD, such as Rift Valley Fever, malaria, and dengue. Other research is related to chemical and biological warfare (including measures to defend against such warfare). DOD funding has also contributed to the development of other technologies that are now critical to the pharmaceutical industry, such as computers and software.

The Department of Veteran Affairs is a large procurer of drugs. It can negotiate with drug companies to lower prices.

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[6] Kokubo, Atsuro, "The Effect of Health Care Policy and Practice on Drug Consumption in Japan and Selected Western European Countries," Spectrum: Health Care Industry (Arthur D. Little), March 1989, p. 1-13 to 1-25.

[7] U.S. Office of Technology Assessment, New Developments in Biotechnology: U.S. Investment in Biotechnology, Washington, U.S. Govt. Print. Off. July 1988. p. 41-42.

Competitive Position of the U.S. Pharmaceutical Industry

The U.S. pharmaceutical industry has been subjected to increasing competition from Europe, particularly West Germany, Switzerland, and the United Kingdom. The Japanese pharmaceutical industry, affected more by pricing practices of the Ministry of Health and Welfare than the policies of the Ministry of International Trade and Industry (MITI), has not until recently been an export-oriented industry. However, Japanese drug companies are expected to become much more of a competitive threat during the 1990s.

Trade

The U.S. trade surplus in drugs had been declining for many years but rebounded in 1990. Imports and exports are now each equivalent to about 10% of the U.S. domestic market for drugs.

Drugs and Medicine Trade Balance
(billions of current dollars)

	Exports	Imports	Balance
1982	$ 2.3 B	$ 1.1 B	$ 1.3 B
1984	2.7	1.7	0.9
1986	3.3	2.3	0.8
1988	4.0	3.7	0.3
1990	5.3	4.2	1.1

Source: 1982-1988: U.S. Department of Commerce, International Trade Administration, United States Trade Performance in 1988. Washington, U.S. Govt. Print. Off. 1989. p. 86. 1990: U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook 1991, Washington, U.S. Govt. Print. Off. 1991.

While assessment of the trade balance in pharmaceuticals is important in analyzing the balance of payments, it is no longer very useful in assessing the competitiveness of the U.S. pharmaceutical industry. The development of overseas facilities means that the industry's sales to overseas customers show up in exports to a much lesser degree than in earlier periods. The diminution of the trade surplus in pharmaceuticals is due in part to this increasing globalization.

Foreign Investment

There is extensive and expanding cross investment between U.S. and foreign pharmaceutical industries. As shown in the table below, U.S. investment in the foreign pharmaceutical industries exceeds foreign investment in the U.S. pharmaceutical industry. U.S. and foreign investment is often done in order to facilitate sales of U.S. products abroad; foreign investment in the United States is often to acquire U.S. technical expertise and marketing operations.

Foreign Investment in the Pharmaceutical Industry
(billions of current dollars)

	U.S. Direct Investment Abroad in Drug Industry	Foreign Direct Investment In U.S. Drug Industry
1984	4.4	2.3
1985	4.9	2.4
1986	6.2	3.3
1987	7.6	3.7
1988	8.4	4.4

Source: Bureau of Economic Analysis, Survey of Current Business, August 1989.

Drug Innovation

U.S. based companies are gradually losing their strong post-World War II technological leadership in the industry. Of sales of the top 36 new chemical entities (NCEs) approved by the FDA and marketed in the U.S. in the 1970s, U.S. based companies had a market share of 82%, compared to a market share of only 62% of sales for the top NCEs of the 1980s. At the same time foreign-based companies more than doubled their share in this critical portion of the U.S. market. Measured by number of drug discoveries, the drop in the U.S.-based companies' share is even greater, from 64% of the NCEs of the 1970s to 39% of the NCEs of the 1980s.[8]

Another measure of innovation is patents. Since patents may not be commercialized, however, they may not be a reliable index of innovations that impact the consumer. U.S.-based companies now account for a much lower share of U.S. patents for drugs and medicines compared to twenty years ago. In the last ten years, however, there has been no clear trend in the share of either U.S.-based or Japanese firms.

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[8] T. H. Althuis, "A Therapeutic and Economic Comparison of the Top Innovative New Drugs of the 1970s and 1980s", Unpublished Study, September 1990. One reason that U.S.-based companies suffered less of a decline in their share of sales than of number of new products is that they licensed 2.5 times as many drugs from foreign sources as in the 1970s.

Shares of U.S. Drugs and Medicine Patents Granted to Inventors in Various Countries

	1963-75	1980	1984	1988	1989
Total # of U.S. Patents	13566	2468	2511	3102	4221
U.S. (#)	8454	1225	1297	1620	2138
U.S. %	62 %	50 %	52%	52%	51%
Japan %	7	11	14	14	14
W.Germany %	8	12	9	9	10
U.K. %	4	8	8	7	7
France %	5	5	4	4	4
Other Countries %	13	14	13	14	14

Source: Office of Documentation Information, U.S. Patent and Trademark Office.

Outlook

The U.S. pharmaceutical industry has lost its once-commanding share of the global market, but its outlook is still relatively healthy. On the positive side, the demand for pharmaceutical industry products is generally expected to increase, due to an aging population around the world, and, over the long term, rising incomes in developing countries.[9]

The U.S. industry is also well-positioned to take advantage of advances in biotechnology and biomedical research, which are making possible increasingly effective drugs. The United States leads in most aspects of this research, and the close links between universities and industry in the United States are a competitive strength.

On the other hand, the pharmaceutical industry can expect to be squeezed by efforts to control health care costs and by the increasing development costs for new drugs. The development costs for drugs have been increasing faster than inflation, going from an estimated $54 million per new drug in 1976 to an estimated $231 million per new drug for drugs developed during the 1970s and early 1980s.[10]

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[9] The Department of Commerce expects the value of pharmaceutical shipments to increase by 2-3 percent per year in constant dollars. U.S. Department of Commerce, U.S. Industrial Outlook 1990. p. 50-4.

[10] Joseph A. DiMasi, Ronald W. Hansen, Henry G. Grabowski, and Louis Lasagna, "The Cost of Innovation in the Pharmaceutical Industry," forthcoming, The Journal Of Health Economics, 1991.

Causes of the rising R&D costs include the need for increasingly expensive and sophisticated scientific equipment and longer development times for drugs, many of which address chronic and degenerative diseases and require longer clinical trials to demonstrate their effectiveness.

International competition can also be expected to intensify. Europe and Japan have learned from the U.S. success in promoting a strong research base for the industry. One indication of the changing nature of competition is in the decreasing number of simple licensing agreements; licensing agreements now often require immediate or future access rights to the new market by the licensor. Japanese pharmaceutical companies have started to become more international. They have been investing and establishing joint ventures in the United States and Europe and have increased their introductions of new chemical entities.

II. CRITICAL TECHNOLOGIES

Technology Development Process

Success in the name-brand prescription drug segment of the pharmaceutical industry depends on a continuous stream of new products that offer some therapeutic advantage over previously existing drugs. To develop these new products, the industry is highly R&D intensive. The members of the Pharmaceutical Manufacturers Association (whose members constitute the U.S. research-based pharmaceutical industry) spent $7.3 billion on R&D in 1989, equivalent to 16.7 percent of sales and exports.[11] These figures include overseas R&D by U.S. companies; U.S.-based R&D was estimated to be $5.9 billion in 1989.

Developing a new drug is expensive and risky, much like prospecting for oil. Drug companies typically screen several thousand chemicals to come up with one successful drug, and on average it takes $231 million (including indirect costs) and 12 years to get a new drug to the market.[12] Although the payoff is potentially large -- a very few drugs have sales as high as 500 million dollars per year -- only a small percentage of new chemical entities make it to the market as new drugs, and only a few of these have sales as large as $100 million per year. Fewer than 30 percent of

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[11] Pharmaceutical Manufacturers Association, 1988-1990 Annual Survey Report, U.S. Pharmaceutical Industry, 1990. PMA's R&D spending figures include both U.S. R&D spending by foreign based companies and foreign R&D by U.S. companies. Because PMA members are the research-intensive portion of the pharmaceutical industry, they have a higher ratio of R&D to sales than the industry has a whole.

[12] Joseph A. DiMasi, Ronald W. Hansen, Henry G. Grabowski, and Louis Lasagna, "The Cost of Innovation in the Pharmaceutical Industry," forthcoming, The Journal Of Health Economics, 1991. Only about half of the $231 million is in direct costs. The rest consists of the "opportunity cost" of tying up the money over time.

NCEs introduced during the 1970s had sales larger than the average R&D cost for a new drug of that cohort of products.[13]

Historically, most new drugs have resulted from an educated trial and error process of testing thousands of substances for therapeutic effects. With better knowledge about the molecular and cellular basis of disease and the effects of drugs, scientists can zero in more quickly and efficiently on the most promising candidates for new drugs. The goal is the "rational design" of drugs for specific therapeutic effects, although in fact the process is still very uncertain. An important part of this process is being able to understand the structure and function of proteins, which are usually the key biomolecules that drugs influence. The techniques of biotechnology are providing powerful tools to isolate and produce these proteins so they can be studied. X-ray crystallography, high powered computers, and software for chemical modeling are becoming powerful tools for studying the structure of proteins and the effects of potential drugs on them. Electron and nuclear spin resonance technology is also important in mapping biochemical reactive sites for the development of promising structural compounds.

Other new drugs can be biologically derived substances, such as hormones, antibodies, and vaccines. In this case, the challenge is to isolate, characterize, modify, and produce existing natural chemicals (or, in the case of vaccines, viruses or bacteria) rather than creating a new chemical. New biotechnology techniques are making possible the production of many new types of biological drugs.

The development of a potential new drug is closely linked to the regulatory process; much of the development work is the testing and clinical trials necessary for Food and Drug Administration (FDA) approval. This process is generally as follows:

1. **Preclinical testing**, which assesses the safety and biological activity of a new chemical entity in laboratory and animal studies. This typically begins one to two years before clinical studies in human subjects can be undertaken and continues in parallel with chronic toxicology studies in animals lasting up to two years, and carcinogenicity and mutagenicity studies being completed after the first human studies have begun.

2. **Investigational New Drug (IND) application** is submitted to the FDA to gain permission to test the drug in human subjects. In this, the drug's sponsor shows the results of preclinical testing and outlines plans for the clinical trials. If FDA does not disapprove the application within 30 days, the drug's sponsor may proceed with clinical trials.

3. **Clinical Trials, Phase I.** These are performed on a test population of 10 to 100 healthy volunteers to determine the safety and the safe dosage range of the drug. Phase I trials also determine the absorption, distribution, metabolism, and excretion of the drugs in humans. This stage takes around a year; about 70 percent of INDs pass this stage.

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[13] Henry Grabowski and John Vernon, "A New Look at the Returns and Risks to Pharmaceutical R&D", Management Science, Vol. 36, No. 7, July 1990.

4. **Phase II Trials.** These are performed on several hundred Patient Volunteers, to evaluate the effectiveness of the drug at different dosages and to continue to look for adverse effects. The trials typically take around 2 years. About a third of INDs pass this stage.

5. **Phase III Trials.**[14] These are performed on 2000-10,000 Patient Volunteers, to verify the absence of side effects at different dosages and in different populations, and to monitor reactions from long-term use. Phase III trials typically take 3 or more years. Twenty-seven percent of IND drugs pass this stage.

6. When sufficient information has been gathered in Phase III trials, the drug sponsor can file a **New Drug Application (NDA)** with the FDA. This application, which includes all supporting data, may be several hundred thousand pages. FDA review for drugs approved in 1989 averaged 32.5 months. Twenty percent of the original IND drugs make it past this stage and are approved for widespread use. In 1989, the FDA approved 23 applications for New Molecular Entities (NMEs); 30 "efficacy supplements", which are requests to use an already approved medicine for additional uses; and 14 Product License Applications (PLAs) for biological products.[15]

7. After **approval**, large scale manufacturing, distribution, education, and post marketing safety monitoring occurs. Phase III trials will continue, to study additional potential uses and to extend the range of available dosage forms.

Drugs are typically patented before the beginning of the regulatory process, and thus 10 or more years of the statutory 17 year period of patent protection have usually passed before the drug reaches the market. The Waxman-Hatch Act of 1984 allowed drug developers to apply for up to five years of additional patent protection to compensate for this time lost while obtaining regulatory approval.[16]

After the patent has expired on a drug, it is subjected to competition from generic drugs. The Waxman-Hatch Act helped to expand the use of generic drugs, and resulted in the pioneer drug manufacturers losing market share more quickly and deeply after their patent expired.

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[14] Under the recently allowed expedited review for new drugs for serious and life-threatening diseases, such as some AIDS drugs, Phase II and Phase III can be combined to give more patients immediate access to promising drugs.

[15] Pharmaceutical Manufacturers Association, "23 New Drugs are Approved; FDA Review Averages 32.5 Months". New Drug Approvals in 1989. January 1990, p. 1.

[16] Flannery, Ellen J. and Peter Barton Hutt, "Balancing Competition and Patent Protection in the Drug Industry: The Drug Price Competition and Patent Term Restoration Act of 1984", Food Drug Cosmetic Law Journal, v. 40, 1985, p. 269-309.

According to a survey conducted by the Pharmaceutical Manufacturers Association, R&D spending by member companies was allocated by function as follows:

Research and Development Allocation of Expenditures by Function

Function	Percent of Total R&D (1988)
Clinical Evaluation: Phase I, II, III	26.4%
Biological Screening and Pharmacological Testing	16.7
Synthesis and Extraction	10.3
Pharmacological Dosage Formulation and Stability Testing	9.1
Toxicological and Safety Testing	7.8
Process Development for Manufacturing and Quality Control	9.1
Other	20.6
	100%

Source: Pharmaceutical Manufacturers Association, 1988-1990 Annual Survey Report, U.S. Pharmaceutical Industry, Washington, 1990, p. 28.

Innovation in the pharmaceutical industry is often characterized as a predictable linear process: basic research is followed by applied research, which leads to the development of a new drug, regulatory approval, and then marketing. Although some new drugs follow this process, much innovation is of a more incremental nature. Some drugs are molecular modification of existing compounds, reformulations of existing drugs, or are new uses of already approved drugs.

Unlike many areas of technology, it takes almost as long to get an incremental improvement to the market as it does to get a breakthrough drug to the market. All drugs must go through the same regulatory process, which accounts for a substantial fraction of the total time before marketing.

Whether a totally new chemical or a modification of an existing drug, it is difficult to predict in advance whether a drug will yield breakthrough therapies, products with more modest advantages over existing products, or any safe and efficacious product at all. Sometimes the most important benefits of a drug are recognized only after use in patients.[17] It is impossible to design research to only produce only breakthrough therapies. Moreover, while some new drugs are quite similar chemically to an existing drug, many offer therapeutically important advantages to the patient in terms of greater convenience or the avoidance of certain side effects.

Early in the drug development process, the FDA rates the potential therapeutic benefit of new drugs in order to prioritize them for review. This system has sometimes been misunderstood to characterize the clinical importance of a new drug. The FDA rating, however, is assigned before the clinical benefits of a drug are well known and is not an accurate measure of pharmaceutical innovation.

Critical Technologies

The technologies (and related fields of knowledge that are critical to the success of the industry) are described on the following pages.

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[17] Postmarketing Development of Medicines, E.S. Snell, Pharmacy International, pp. 33-37 (vol. 7, no. 2, 1986); Pharmaceutical Research: Therapeutic and Economic Value of Incremental Improvements, R.A. Levy, National Pharmaceutical Council, (1990), Reston, VA.

CRITICAL TECHNOLOGY: Biomedical Research Base for Drug Discovery and Development

DESCRIPTION: The knowledge and skill base in the fields of science that are essential for drugs discovery and development. This includes research into the pathophysiology of various diseases and processes (especially aging, heart disease, cancer, AIDS); various branches of human physiology; molecular and cellular biology, including studies of the relationship between chemical structures and their bioactivity; physical chemistry; synthetic organic chemistry; protein chemistry and structure; toxicology; pharmacology; immunology. This knowledge base is largely embodied in the education, training, and experience of researchers.

WHY IS IT A CRITICAL TECHNOLOGY? The key to success in the pharmaceutical industry is discovering significant new drugs. The discovery of these drugs is dependent on and follows directly from basic discoveries in the biomedical and chemical sciences, through painstaking search for implications and refinement of applications. It is the substantial research commitment of government, academia and industry, aided by relatively free interchange of information, that creates the research infrastructure, which in turn supplies both the knowledge base and the skilled people necessary for further advance.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000		X	

The U.S. share of world scientific and technical articles in the fields of clinical medicine and biomedicine has remained virtually constant since 1973, at 41 and 39 percent, respectively,[18], which is one indication that the U.S. research base for the pharmaceutical industry is not declining relative to the rest of the world.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: The U.S. research infrastructure is threatened by weaknesses in U.S. pre-college science education and the low number of U.S. students pursuing advanced training in the sciences. Federal budgetary pressures, on the one hand, and a constriction of private industry's funds available for research and development, on the other, threaten to hold research funding below appropriate levels.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: The areas of biomedical research are all closely related, and all fields are increasingly being understood in biochemical terms. Biotechnology techniques, advanced scientific instrument, computer modeling, and databases are technologies that are critical to the advancement of this research.

POLICY ISSUES: Federal funding and conduct of R&D by the National Institutes of Health, National Science Foundation, the Department of Energy and other agencies. Science education programs at the Federal, state, and local level. Availability of support for graduate research in the life sciences.

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[18] National Science Board, Science & Engineering Indicators - 1987, Washington, U.S. Govt. Print. Off. p. 286.

CRITICAL TECHNOLOGY: Biotechnology

DESCRIPTION: Techniques involving the manipulation of the genetic composition of living organisms for useful purposes, including recombinant DNA, hybridomas (cell fusion), and bioprocessing techniques. These techniques are used to produce proteins, peptides, nucleic acids, and genetically altered plants, animals and microorganisms.

WHY IS IT A CRITICAL TECHNOLOGY? Biotechnology techniques are an integral part of biomedical research, particularly in producing, studying, and modifying proteins and peptides, and clarifying the structure of receptors and enzymes. Biotechnology techniques also enable the development and production of new drugs, such as vaccines, monoclonal antibodies, hormones, and interferons. They also are used to develop new diagnostic techniques and transgenic animals (animals with altered genes), which may more accurately mimic human diseases and responses to drugs. Human genome sequencing will aid in the understanding of diseases with a genetic basis and in the development of drugs to treat those disease. Bioprocessing is critical for producing large volumes of drugs at low cost.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000		X	

Patent data shows little evidence of erosion of the U.S. lead in biotechnology. 36 percent of U.S. biotechnology patents (broadly defined) were granted to foreigners in 1988, down from 38 percent in 1987 and 39 percent in 1986.[19] Of genetic engineering patents for health care/pharmaceuticals, only 15 percent were assigned to foreigners.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: The U.S. regulatory environment currently favors the U.S. relative to Europe; a more restrictive U.S. regulatory environment would hurt research in the U.S. A lack of attention to bioprocessing hurts the U.S. in areas where production costs are more important than product development, such as in bulk pharmaceuticals and generic drugs.

Diversion of talent from basic research and teaching could weaken basic research and training of new researchers. In addition, weaknesses in the science education pipeline may lead to too few top researchers.

The weak financial resources of some U.S. biotechnology companies often lead them to license their products or sell equity in their companies to foreign companies. This provides resources to continue conducting research in the United States, but transfers technology, which often is based partially on government-funded research, abroad.

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[19] Copmann, Thomas L., "PMA Patent Analysis Tracks Trends in Biotechnology Research", Biotechnology Medicines, Pharmaceutical Manufacturers Association, 1989 (no pagination).

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on research in genetics, cellular and molecular biology, immunology, virology, chemistry, pharmacology and on scientific instruments. Bioprocessing depends on advanced sensors and process control, and on purification technologies.

POLICY ISSUES: Federal research funding, especially the $3.3 billion of support for biotechnology research by NIH in (FY1991)[20]; science education; university-industry-relationships; federal policies regarding technology transfer and conflict of interest regulations; federal biotechnology regulatory policies; patenting of biotechnology; Human Genome Project; foreign investment in biotechnology industry.

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[20] Budget of the U.S. Government, FY1992, Washington, U.S. Govt. Print. Off., July 1991, part 2, p. 72.

CRITICAL TECHNOLOGY: Scientific Instruments and Equipment and Techniques

DESCRIPTION: Instruments, equipment, and associated techniques used in biological and chemical research. Of particular importance to the pharmaceutical industry are instruments for making in vivo measurements of biological reactions and for elucidating the structure of large peptides, proteins, and biomolecules. Key instruments and techniques include nuclear magnetic resonance (NMR), electron paramagnetic resonance, and other types of spectroscopy; mass spectrometry, X-ray crystallography, electron microscopes, biosensors, and automated equipment for gene and protein sequencing.

WHY IS IT A CRITICAL TECHNOLOGY? State-of-the-art scientific instruments are essential to conduct state-of-the-art research and instruments with new capabilities often lead directly to advances in science and technology. Such instruments can accelerate the rate of laboratory experimentation or produce results with greater precision or specificity. Delayed access to leading-edge equipment could prevent pharmaceutical companies from being at the leading edge of drug development.

Automated instruments can help improve research productivity, especially in areas where large numbers of increasingly complex measurements are becoming the norm.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990	X		
2000	X		

U.S. companies no longer make the most advanced versions of most types of scientific instruments. U.S. companies are competitive in mass market instruments.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: U.S. instrument makers have withdrawn from the high end of the market for many advanced instruments to concentrate on the larger portions of the market. The high costs, uncertain markets, and U.S companies' need for a high return on investment hurt U.S. leadership in scientific instruments.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Development of improved scientific instruments depends on research on the phenomena being studied, and on basic research in physics, chemistry, microelectronics, optics, and advanced sensors.

POLICY ISSUES: National Institutes of Health funds research on scientific instruments and provides grants to help research institutes purchase expensive instruments through its Shared Instrumentation Grant Program ($32 million in FY 1989). The National Institute of Standards and Technology (NIST) conducts research on measurement technologies; some research in DOE labs may also contribute to advanced instrumentation.

CRITICAL TECHNOLOGY: Computers and Computational Chemistry Software.

DESCRIPTION: Supercomputers, graphics workstations, and the software used to model molecules. These tools are used to determine the three-dimensional structure and molecular dynamics of large molecules based on analogies to known molecules and calculations based on the energy fields of their component atoms.

WHY IS IT A CRITICAL TECHNOLOGY? Computer modeling helps scientists define the structure of new drugs and biomolecules that drugs are intended to affect. It allows better estimation of the performance of a potential drug without physically creating and testing the drugs. This enables scientists to design compounds more likely to demonstrate activity in relevant biological models and to design agents more likely to exhibit potent, specific interaction. Graphic workstations that interface with high-speed computers allow three-dimensional color visualization of the structure of molecules and how these might interact with one another, stimulating new ideas about potential drug chemical structures. Faster computers and improved software make it possible to run more sophisticated models that better predict the structure and motion of macromolecules in solution.

U.S. POSITION RELATIVE TO RoW:

		Lag	Par	Lead
C = computers	1990		C	S
S = software	2000		C	S

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: U.S. supercomputer makers are financially weaker than their Japanese competitors. The high development cost combined with a higher cost of capital in the U.S. may contribute to relatively less investment in computer development than in Japan. Supercomputers are a targeted industry in Japan. (See sectoral profile on the computer industry.)

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Leadership in computers and computational chemistry depends on the health of the computer, microelectronics, and software industries (and particularly the parts of those industries specializing in biomedical applications). It also depends on excellence in such as academic fields as numerical analysis (applied math), chemistry and biochemistry. Improvements in artificial intelligence and neural networks will help chemists get more information from calculations. (See also sectoral profile on the computer industry.)

POLICY ISSUES: NSF and DOD R&D funding for computers and software; supercomputer network infrastructure; NIH funding of biomedical computing research.

CRITICAL TECHNOLOGY: Databases and Communication Networks

DESCRIPTION: Databases on genetic sequences, protein sequences, x-ray structures, results from clinical drug trials; high-speed computer networks to rapidly transmit information; and software to aid in identifying and retrieving relevant information.

WHY IS IT A CRITICAL TECHNOLOGY?
Databases are important in developing relationships between the structure and activity of potential drugs, and in accessing, analyzing, and managing information on the effects of drugs in clinical trials. Databases and communication networks can potentially give researchers rapid access to the relevant public data on a topic, reducing unnecessary mistakes and duplication in experiments.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000		X	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
The globalization of databases and the increasingly rapid worldwide dissemination of information is eliminating the advantage accruing to the country that develops the database, and is making it easier for others to profit from U.S. basic research.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Depends on computers, software, and high-speed computer networks. Interdependencies with various telecommunications policy issues. Software incorporating some aspects of artificial intelligence is helpful in retrieving and analyzing information from databases.

POLICY ISSUES:
Federal funding for databases, such as the Protein Data Bank at Brookhaven National Laboratory, the Biotechnology Information Center at the National Library of Medicine of NIH, and the "GenBank" genetics database at NIH. Federal support for a supercomputer network. Global sharing of databases.

CRITICAL TECHNOLOGY: Artificial Intelligence and Neural Networks

DESCRIPTION: Includes expert systems, which encode expert knowledge, and neural networks, which are designed to "learn" from data to recognize patterns.

WHY IS IT A CRITICAL TECHNOLOGY? Artificial intelligence and neural networks are useful in interpreting experimental results and can aid both design and operations by providing encoded expert advice. They can help improve analysis and interpretation of data. They can also be used to help transfer expert knowledge from one part of a corporation to another, and share expertise between generations of scientists.

Neural networks are useful for pattern recognition (a weakness of traditional computers and software), which is useful in interpreting biological, chemical and clinical data, and provides input for decision making.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		X	
2000		X	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Shortage of artificial intelligence researchers and engineers. Dedicated efforts in Japan and Europe.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Related to databases, computer hardware and software, biological and cognitive sciences. DOD funding and applications are important.

POLICY ISSUES: R&D funding; science and technology manpower issues.

CRITICAL TECHNOLOGY: Drug Delivery Technologies

DESCRIPTION: Techniques to enhance and simplify drug therapy and reduce unpleasant or harmful side effects of drugs. Examples include transdermal patches, time release capsules, and techniques to enable the administration of protein substances without the need for injections. Research is on sustained and controlled release technologies, transmucosal, transdermal delivery systems, implantable pumps and polymeric systems. Research is also developing ways of getting drugs to specific sites in the body.

WHY IS IT A CRITICAL TECHNOLOGY? Drugs that are more convenient or effective, or that have fewer side effects, have a competitive advantage over other drugs. Drug delivery technologies are particularly important for biotechnology-produced drugs, which are proteins or peptides that cannot be administered orally.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			X
2000		X	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Any factor that undermines drug development -- loss of research funding, inefficient regulatory approval processes, lower private R&D, etc.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Closely related to work on advanced materials and membranes; requires advanced scientific instruments and is dependent on biomedical research. Two other issues are the design of prodrugs and the development of carrier molecule technology such as antibodies.

POLICY ISSUES: Research funding; drug price controls; FDA regulatory policy with respect to therapeutic equivalence; reimbursement policy.

III. CRITICAL ISSUES

Research Funding and Priorities

Continued strong federal and industry support for biomedical research is critical. The current level of funding by the research-based pharmaceutical industry ($7.3 billion yearly) has in recent years surpassed funding by the U.S. government's National Institutes of Health (NIH) ($7 billion). Additional medical-related research is funded by the National Science Foundation, Department of Defense, and other agencies.

Although NIH funding is by no means exclusively targeted for research on drugs, it has contributed substantially to the advancement of knowledge that underlies the most significant new drugs. In addition, this funding has created strong universities, medical schools, and other research institutions, and it supports the training of researchers.

The United States spends a far greater percentage of national government R&D on health-related research than do its main competitors:

Percent of Government R&D Spending for Health (1987)

United States	11.9
Japan	2.4
West Germany	3.2
France	3.6
United Kingdom	4.3

Source: U.S. National Science Foundation, International Science and Technology Data Update: 1988, Washington, 1988, p. 10.

Other countries spend less on basic research but target research that is more directly related to industry needs. For example, the Japanese government has identified biotechnology as a key technology for competitiveness, supports the organization of industry research associations to spread non-proprietary knowledge throughout the industry, and provides tax incentives and loans for research and for the commercialization of technology.[21] There is more emphasis on bioprocess engineering than in the United States, and Japan leads the United States in some aspects of bioprocessing.[22]

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[21] Yoshikawa, Aki, "The Other Drug War: U.S.-Japan Trade in Pharmaceuticals," California Management Review, Winter 1989, p. 76-90. Also, Tanaka, Masami, "Government Policy and Biotechnology in Japan: The Pattern and Impact of Rivalry Between Ministries," unpublished manuscript, 1989.

In Europe there are both European Community (EC) research programs and national research programs. Among the EC programs are the Biotechnology Research and Innovation for Development and Growth in Europe (BRIDGE) program, and the programs sponsored by the European Research Coordination Agency (EUREKA).[23] The United Kingdom is regarded as strong in basic research but relatively weak in the commercialization of technology.[24] West Germany has strong industrial biotechnology research in its large chemical and drug companies and effective links between these companies and government-supported research institutes.

Equally important is the maintenance of private industry research efforts. Only if the U.S. pharmaceutical industry's income from research-based new drugs is not unduly constricted will its ability to fund research be sustained. Both federal budget constraints and various public policy initiatives, as represented by the recent Medicaid rebate legislation and by the policy of promoting the use of generic drugs, are threatening to reduce this source of funding.

One measure to encourage private sector R&D is the Orphan Drug Act of 1983. This act provide tax incentives and seven years of market exclusivity to the first company receiving FDA approval for a designated orphan drug, defined as one to treat a disease affecting 200,000 or fewer individuals in the United States. The Act is proving to be especially beneficial to the development of biotechnology-produced drugs that otherwise might not be able to obtain strong patent protection.

Intellectual Property

The existence of strong U.S. patent laws has been a major benefit for the research-based pharmaceutical industry. There are several intellectual property issues relevant to the pharmaceutical industry.

Uncertainty concerning biotechnology patent law. Many highly technical biotechnology patent issues have not yet been resolved and there are conflicting patent claims on many potentially important new drugs. The U.S. Patent and Trademark Office uses four criteria in judging a patent: the invention must be novel, it must possess utility, it must be non-obvious, and the patent must enable others to use the invention.[25] Biotechnology products often have the most difficulty with the non-obvious criterion. Typically, the patents are on the process rather than the product, which is often an unpatentable natural protein. A key question in many patent disputes is to what extent the process of producing a protein, once it is discovered, is obvious and thus unpatentable.

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[22] Yoshikawa, Aki, "The Other Drug War: U.S.-Japan Trade in Pharmaceuticals," California Management Review, Winter 1989, p. 76-90.

[23] U.S. Congress, Office of Technology Assessment, Mapping Our Genes -- The Genome Projects: How Big, How Fast?, Washington, U.S. Govt. Print. Off., April 1988, p. 139-148.

[24] Oppenheimer, Michael F., and Donna M. Tuths, NonTariff Barriers: The Effects on Corporate Strategy in High-Technology Sectors, Boulder, CO, Westview Press, 1987. p. 41-59.

Patent Piracy. U.S. pharmaceutical companies estimate that they lost $2 billion to patent pirates in 1988, primarily in newly industrialized countries.[26] U.S. companies would benefit from stronger international enforcement and stronger patent laws.

Consistency in International Patent Law. Foreign patent laws differ significantly from those of the United States with respect to: (1) when information in the patent application is made public; (2) whether priority goes to the first to invent (as in the United States) or first to file a patent (as in Europe and Japan); (3) the extent to which new life forms and processes can be patented; and (4) what constitutes patent infringement.[27] These inconsistencies lead to the conflicts, costs, and the possible loss of intellectual property.

Drug Pricing Policies

Many developed countries have national health insurance programs that control the price of drugs. In general, such programs reduce the ability of home-nation drug companies to recapture the cost of R&D and fund the next round of drug development. Since new drug development is the essence of dynamic competition, price control systems impede the effectiveness of drug companies in global competition. Some countries' policies try to accommodate this need. Japan's national health insurance program, for example, is designed to maintain an incentive for innovation, by allowing higher prices and profits on new drugs than on old drugs. [28]

The lack of such price controls in the United States is a relative advantage for U.S. companies but also attracts companies from other countries to the U.S. market. There are, nevertheless, increasing pressures to constrain drug prices in the United States, primarily through (1) the greater negotiating power of large drug purchasers; (2) the increased consideration of cost as a factor in choosing among drug therapies; (3) the increased use of generic drugs; and (4) the recently mandated rebates to states for Medicaid purchases. While all of these pressures may reduce the profits for drugs for which there is substantial competition, all but the fourth can be expected to have less effect on drugs that provide significant benefits over other drugs on the market.

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[25] Baum, Rudy M. Biotech Industry Moving Pharmaceutical Products to Market, Chemical and Engineering News, July 20, 1987, p. 11-32.

[26] U.S. Department of Commerce, International Trade Administration, 1989 U.S. Industrial Outlook, Washington, U.S. Govt. Print Off. 1989. p. 16-1.

[27] Oppenheimer, Michael F., and Donna M. Tuths, NonTariff Barriers: The Effects on Corporate Strategy in High-Technology Sectors, Boulder, CO, Westview Press, 1987. p. 41-59.

[28] Yoshikawa, Aki, "The Other Drug War: U.S.-Japan Trade in Pharmaceuticals," California Management Review, Winter 1989, p. 76-90.

Science Education

Because the competitiveness of the pharmaceutical industry depends on the quality of scientists in the industry, the quality of U.S. science education is critical to the success of the industry. Although the U.S. university system is still regarded as the best in the world, there are weaknesses in U.S. science education at all levels. U.S. students show lower levels of achievement in math and sciences than do students in many other countries, fewer U.S. undergraduate college students major in science, and fewer college science majors choose to pursue advanced science degrees, Thus, U.S. citizens currently receive only half of the science and engineering Ph.D.s awarded by U.S. universities. In addition, the decline in financial and professional opportunities in academia relative to industry is drawing faculty away from teaching and basic research in universities, weakening the training of graduate students.

University/Industry/Government Roles in Research

In the past, the roles of universities, government, and industry in research were fairly well defined: universities conducted basic research and educated students; the federal government funded basic research in universities and in NIH's intramural laboratories and clinics and conducted applied research in areas of national priority that the private sector underfunded; and the private sector conducted research and development that led to proprietary products. In many areas of research related to the pharmaceutical industry, however, these divisions are increasingly less clear. Areas of commercial profitability are very close to areas of basic research, and the activities of universities, government, and industry increasingly overlap. Universities and the government conduct research that leads directly to commercial products, and pharmaceutical and biotechnology companies fund research that could be considered basic research.

Some of these blurred roles may not be appropriate, as some institutions end up performing functions for which they are not ideally suited. To the extent that limited Federal dollars go to applied research, fewer go to basic research, and private industry will need to conduct more basic research, which is not the most efficient use of industry money.

The fundamental basis of the biotechnology industry is the healthy relationship between the NIH, universities and the private sector. One significant reason that we are ahead of the Europeans and the Japanese in biotechnology is the relatively unhampered flow of information and technology between these three sectors. Recent changes have both aided this interchange and threatened it. The various technology transfer laws (Stevenson/Wydler and Dole/Bayh) have had an important role in the commercialization of government-funded inventions and the evolution of the biotechnology industry. On the other hand, overly restrictive rules regarding potential conflicts of interest of researchers could put unnecessary hurdles between NIH-funded researchers and the private sector. An appropriate solution is to full and timely disclosure of the relevant information to authorities at the university or research institute, who will then work to resolve the apparent conflicts.

Cost of Capital

Because drug development involves tying up substantial amounts of money for a number of years before any payback, the cost of capital is a significant part of the cost of drug development. Roughly half of the total cost of drug development is the "opportunity cost" of money invested over time.[29] The United States has a higher cost of capital than most other industrialized countries, especially Japan and West Germany, [30] which makes investments in R&D more expensive for U.S. companies than for companies in Japan and West Germany. The disparity is caused by differences among the three countries in savings, in the relation of banks to industry, in tax policy, and in government responses to corporate distress.[31]

The United States has several policies to lower the cost of R&D to companies. The R&D tax credit lowers the cost of incremental increases in R&D to companies. This tax credit has not been made permanent, however, and the uncertainty about its future prevents companies from counting on it in their long-term planning. The Bush Administration proposes to make the R&D tax credit permanent, which would help lower the cost of R&D in the United States.[32] Congressional actions to provide a more sensible rule, in lieu of previous IRS regulations, for the allocation of research expenses between U.S. and foreign income should also be made permanent. In addition, the Orphan Drug Act of 1983 provides incentives for drug manufacturers to conduct research on drugs that would not otherwise be profitable. The Act provides for a tax credit for some orphan drug development costs and provides the drug's sponsor with seven years of exclusivity in the marketplace. The Act is proving to be beneficial to the development of biotechnology-produced drugs that otherwise might not be able to obtain strong patent protection.

Japan has an R&D tax credit similar to that of the United States, and also has additional channels to low cost capital for biotechnology research. One such source is the Japan Key Technology Center, which provides capital investment to organizations established for cooperative R&D, and provides interest-free loans for

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[29] Pharmaceutical Manufacturers Association, Facts at a Glance, 1989, p. 13.

[30] McCauley, Robert N., and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital", FRBNY Quarterly Review (Federal Reserve Bank of New York), Summer 1989, p. 7-28.

[31] Ibid.

[32] U.S. Executive Office of the President, Office of Science and Technology Policy, "Science and Technology in the President's FY 1991 Budget," (Press Statement) Washington, January 29, 1990. p. 4.

R&D. Another source is the Japan Development Bank, which provides low-interest financing for the development and commercialization of technology.[33]

Controls on Research and Use of Experimental Animals

The United States is increasingly regulating several aspects of scientific research, such as laboratory safety and the use of laboratory animals and fetal tissue in research.[34] While many of these regulations address valid concerns, they make biomedical research more time-consuming and expensive, and increase the cost of developing new drugs. These costs should be considered and, to the extent possible, minimized when designing regulations.

West German regulatory policies with respect to biotechnology research are more restrictive than U.S. policies. A West German court has ruled that because West German law does not "expressly permit the application of genetic engineering, such facilities may not be built and operated."[35] These policies have encouraged German companies to set up research laboratories in the United States. Draft EC directives on biotechnology would also treat biotechnology products more stringently than do U.S. regulations, which appropriately seek to regulate products based on their hazards, not on how they were produced.[36]

Regulatory Environment for Drugs

The U.S. regulatory environment has both strengths and weaknesses in promoting competitiveness compared to other countries. The U.S. has a long and rigorous drug approval process and the FDA takes a longer time in reviewing drug applications than do regulatory agencies in other countries. On the one hand, this long regulatory approval period delays the time when patients can benefit from the drug, accentuates the effect of high capital costs, and increases the development costs for the drug. Reducing the time for regulatory approval has a 5-6 fold greater value in generating cash flow for reinvestment in R&D than adding the same amount of time to the period of patent protection.[37] The long regulatory approval time also encourages drug companies to perform clinical trials in other countries. Therefore, decreasing the time required for regulatory approval is a high priority in reducing drug development costs. On the other hand, the U.S. regulatory process has prevented some harmful drugs from reaching the market, and this, combined with the openness of the regulatory process, seems to have led to somewhat greater public confidence in the safety of drugs.

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[33] Agency of Industrial Science and Technology, 1988, Tokyo, Ministry of International Trade and Industry, 1988.

[34] These are discussed in U.S. Congress, Office of Technology Assessment. The Regulatory Environment for Science. Washington, U.S. Govt. Print. Off. February 1986.

[35] Bachtler, Barbara, "Court Blocks German Biotech Plant," Science, November 17, 1989, p. 881.

[36] Thomas L. Copmann, Pharmaceutical Manufacturers Association, personal interview, January 17, 1990.

[37] Grabowski and Vernon, "Pioneers, Imitators, and Generics--A Simulation Model of Schumpeterian Competition", The Quarterly Journal of Economics, August 1987.

Pressure from AIDS activists has encouraged the FDA to make significant new AIDS drugs available to patients faster than before (by making drugs more widely available after or during the second phase of clinical trials rather than after the third phase). This change could set a precedent for accelerating the regulatory process for drugs for the treatment of life-threatening or chronically disabling diseases. If there should be significant adverse reactions to one of these fast-cleared drugs, however, there could be a backlash and regulatory approvals might be slowed down.

The U.S. pharmaceutical industry generally supports increased resources for FDA.[38] Recently, industry has been joined by voluntary associations representing patients and by professional groups representing clinicians and researchers in asking for greater funding for the FDA. Staffing and funding in constant dollars dropped significantly at FDA from 1979 to 1987. This occurred despite an increase in regulatory responsibilities under law. Since 1987, both staffing and funding have increased somewhat, with most of the increase going to AIDS activities. The rest of the Agency has languished, however, and staffing is still nowhere near 1979 levels.[39] Greater funding is needed to raise salaries in order to attract and retain competent staff and to modernize, upgrade, and consolidate the agency's physical plant, much of which is deteriorating, badly cramped, and geographically dispersed. Greater technical resources are needed, such as modern laboratory equipment and computers to assist the scientific staff in its drug evaluation work. Moreover, the agency's workload is expected to double in the next 15 years.[40] Without significantly greater funding and staffing, it is very likely that drug approval times will increase substantially, to the detriment of the U.S. pharmaceutical industry and the public at large.

Product Liability

The product liability environment in the United States and the cost of insurance to protect against lawsuits raises costs and inhibits research in certain areas, particularly vaccines, oral contraceptives, and medical devices. According to the Department of Commerce, only half as many U.S. companies produce vaccines as 20 years ago, largely due to product liability concerns.[41] On the other hand, medical malpractice liability increases demand for diagnostic services produced by biotechnology and pharmaceutical firms, but this increases health care costs.

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[38] Pharmaceutical Manufacturers Association, "23 New Drugs are Approved; FDA Review Averages 32.5 Months", New Drug Approvals in 1989. January 1990, p. 1.

[39] Government Executive, May 1990, pp. 12-17.

[40] Comments of the FDA Counsel before the Subcommittee on Drugs and Biologics, HHS Advisory Committee on Food and Drug Administration.

[41] U.S. Department of Commerce, 1989 U.S. Industrial Outlook, Washington, U.S. Govt. Print. Off. 1988. p. 16-2.

Trade Policy

Non-tariff barriers in many countries, including the United States, encourage companies to invest and establish joint ventures globally. Safety regulations and hard-to-penetrate drug distribution systems are among the main barriers. For example, prior to 1986, the export from the United States of non-FDA approved drugs was prohibited. Legislation adopted in that year permits the export of such drugs to countries where the drug has been approved and the country has a regulatory approval process of roughly the same thoroughness as the U.S. process.

IV. SUMMARY

The discovery of new drugs builds upon basic advances in the biomedical and chemical sciences by focusing these insights on finding and characterizing new products. The discovery process also responds to feedback from the clinical and marketing environment and to tangible financial incentives. The strong U.S. position in pharmaceutical innovation is therefore the result of the combination of three elements: strong U.S. government support of biomedical research; the intensity of the U.S. pharmaceutical industry's commitment to research; and the relatively unfettered flow of information among government, academic and industry researchers. The robust U.S. research infrastructure encompasses an excellent standard of clinical practice and medical and scientific education as well. Constraints and opportunities in the U.S. market have a greater impact on U.S.-based companies than on foreign companies because U.S. firms' domestic sales are a greater share of their total sales and because their senior management are in closer contact with U.S.-based researchers and policy makers.

Strong federal support for biomedical research, including the $7 billion annual funding of the National Institutes of Health (NIH), has been a major competitive advantage for the industry. The U.S. government spends far more on basic biomedical research than does any other country, and U.S. universities are considered the best in the world in biomedicine. The NIH contributes substantially to the advancement of biomedical knowledge and, equally important, to the training of researchers.

The U.S. market is a powerful stimulus to pharmaceutical research, particularly for U.S. based companies. This is due to strong patent protection but also to a market-based system for pricing, which makes possible returns commensurate with risks and benefits. This is especially important because the industry's research and development is funded by the earnings of its new drugs.

The U.S. has stronger connections between university and government research labs than do most other countries. Similarly, information flows between government-supported and industry researchers have been relatively free, enhancing the productivity of all researchers.

Strong as the U.S. pharmaceutical industry is, there are warning signs of threats to the biomedical research infrastructure. Despite strong federal support for biomedical research, prominent scientists warn that America's funding commitment has not kept pace with the growing complexity and cost of research. At the same time, other countries are targeting biomedical research for special government support and are learning to profit from U.S.-conducted basic research. U.S. science education is weak, especially at the pre-college level, and the pool of scientific talent is not being adequately replenished. The industry's ability to sustain its research commitment is threatened as returns from new drug development are squeezed by public policy initiatives, such as the recent Medicaid rebate legislation and the policies accelerating the increase in use of generic drugs. Weak intellectual property protection abroad saps the industry's ability to earn a sufficient return on its research and development. Finally, undue concern about researchers' conflicts of interest could lead to policies that would jeopardize the flow of information among government, academic and industry researchers.

Three policy issues demand special vigilance. First, science education is lagging badly and must be strengthened. Second, intellectual property rights are inadequately protected, especially in the international arena. Third, new federal programs that increase the U.S. pharmaceutical industry's costs, reduce its revenues or make it more difficult to research, develop and obtain approval for new products will adversely affect its international competitive position.

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

This research paper was prepared by Council Senior Associate David W. Cheney. Frederick Telling and Allison Keith of Pfizer, Stanley Fidelman of Merck, and Virginia Weldon of Monsanto greatly contributed to the paper.

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ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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A COMPETITIVE PROFILE OF THE

ELECTRONIC COMPONENTS AND EQUIPMENT INDUSTRY

Research Paper for

GAINING NEW GROUND:

TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future*.

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling and $20 for *Gaining New Ground* plus $2.50 postage and handling.

Electronic Components and Equipment

SECTORAL PROFILE

Summary

The electronics industry has been an area of strength in the U.S. economy. U.S. firms have led the world in devising and reducing to practice much of modern electronics technology. While the U.S. electronics industry retains leadership in some aspects of the business (such as systems integration and communications equipment), it is increasingly threatened or has lost control of other, important product fields.

Key Characteristics

* Electronics is a global industry of major importance to modern industrial economies; its impact extends to many non-electronic businesses. The growth rate of electronics businesses is likely to continue to be greater than that of other major industries.

* Development of a native electronics industry, capable of competing in world markets is the focus of many countries' industrial plans, following the Japanese model.

* The electronics industry structure is a "food chain" extending from raw materials and production equipment to products and integrated systems. The health of each link in this chain is critically dependent upon the condition of adjacent industry segments and on the strength of vendor-customer relationships within the industry.

* Parts of the electronics industry are very capital intensive; long term investments in R&D and plants and equipment are required to compete. High fixed capital costs make autonomous components, materials and production equipment concerns extremely sensitive to large, unpredictable market fluctuations.

* The electronics industry is driven by sophisticated, rapidly changing technology which moves easily around the world, and by volume manufacturing experience. Product and manufacturing process life cycles are becoming shorter.

* Company needs for rapidly changing technical and production skills demand a literate work force and up-to-date professional skills.

* Changing technology, manufacturing requirements and industry R&D structure demand basic changes in business time horizons and new management techniques to adapt to different ways of doing business.

Factors Supporting the Competitiveness of the U.S. Electronics Industry

* The United States has a history of innovation on the electronics field; virtually all major systems and device concepts originated in the United States. This inventive strength persists, but is now seriously threatened.

- North America remains the world's largest open market for Original Equipment Manufacturer (OEM) equipment. U.S.-based companies remain among the world's largest OEM equipment producers.

- The United States continues to be the leader in formation of new electronics companies, at all levels of the industry. Many of these small companies are leaders at rapid commercialization of new product concepts.

- The United States continues to lead in important electronics-related technologies, such as system integration, software, some types of computer peripherals (such as magnetic disks), and processor architecture. However this position is seriously threatened from abroad.

Factors Weakening the Competitiveness of the U.S. Electronics Industry

- The U.S. electronics industry structure, unlike that of competing countries, consists mainly of autonomous (not related to up- or downstream) firms. This structure is especially fragile because of weak materials and production equipment firms.

- The perception of the relative high cost of capital available to U.S.-based firms is a significant disadvantage in fields as capital intensive as semiconductors, electronic materials and production equipment. The long investment horizons required for electronics components and basic fabrication technologies makes the electronics industry particularly sensitive to high cost, impatient capital.

- Access by U.S. electronics firms to critical markets abroad, especially in Japan, is restricted by public and private practices intended to favor national suppliers. These practices restrict opportunities for U.S. firms to become or remain world leaders in many electronics areas.

- U.S. firms have turned away from important commodity products, such as consumer electronics and dynamic RAMs, and are behind Asian competition in volume manufacturing experience and hence in designing for volume manufacture.

- U.S. producers have generally failed to recognize the importance of developing skills and processes for high quality, cost-effective production to capitalize on their product innovations.

- The U.S. processing equipment and electronic materials supplier base has lost leadership in world markets, leaving American components producers reliant on foreign suppliers, many of whom are competitors.

- The present U.S. leadership weakness in setting worldwide standards for electronic systems operation hampers U.S. firms in developing new products.

- The advantage of a large, mobile, skilled work force, once enjoyed by U.S. firms is no longer unique. American producers now face off-shore competitors whose employees are as skilled, on average, as theirs.

Key Insights for the National Technology Strategy

- Ability of one level of the electronics industry structure to cross-subsidize business investments in another level, which rests on a series of dissimilar technologies, can be an important factor in the overall strength of the industry. Effective vendor-customer relationships are critical to the strength of the overall structure.

- Failure to sustain a strong core of basic research capability and activity and to harness it effectively to meet market needs will diminish our technological resources for development and commercialization of new products and processes.

- Failure to continue investing in critical manufacturing-based businesses will provide opportunities for foreign competitor entry and possible dominance of more sophisticated markets.

- Failure to educate and restructure management to take on the tasks of managing increasingly complex development, integration and manufacturing processes may abort the creation and application of new processes and materials necessary for long-term growth and strength.

- Military technology, once an important driver of progress, is no longer the dominant source of new technology for civil applications.

- A future U.S. technical work force capable in competence and size to staff anticipated electronics industry needs is not in sight.

Critical Technologies

- Sub-micron Technology - Tools, processes and device structures for semiconductor products having critical dimensions less than 0.5 micrometers.

- Optoelectronics Technology - Materials, components and techniques for using light for high performance information transmission and switching.

- Efficient, high quality, reliable, high volume equipment and device production skills.

- Packaging and interconnection technology from the component to the system level, including techicques for protecting, cooling and conveying signals and power throughout an electronic system.

- Electronic materials technology encompassing the entire range of materials comprising electronic components and used in their fabrication.

- Computer aids to design and engineering simulation of performance at all levels: processes, devices, circuits and systems.

- Integrated circuit memory technology comprising both the design and fabrication process techniques needed to produce high density, high speed, reliable memory chips.

- Integrated circuit logic technology -- the collection of device and process technologies used to fabricate integrated digital logic chips.

- Display technology -- the collection of various technologies used to present images on flat surfaces for user viewing.

Background

The electronics industry provides systems hardware (and constituent subsystems, components and materials) which acquire, process, store, communicate and display information and provide control capability. Since the emergence of electronics technology in the 1920's, the industry has grown to become one of the American economy's largest sectors, providing 7.6% of all U.S. manufacturing shipments in 1986.[1] The electronics and related industries now employ 2.6 million workers in the United States.[2]

In order to present a complete picture of the electronics industry, because of the broad impact of electronics hardware, some of the considerations discussed in this profile will overlap those of other sectors, in particular, computers and telecommunications.

Electronics has become a major activity of today's industrialized nation. The principal segments of the electronic products industry (computers, telecommunications equipment, consumer electronics, industrial electronics and instrumentation, transportation equipment and military electronics) produce $650 billion worldwide annual sales.[3] In addition, **electronics technology is a driving force behind advances in many other product areas: spacecraft, numerically-controlled machine tools, aircraft navigation equipment, automated bank tellers, medical CAT scanners and the electronic engine controls needed to meet automotive pollution, customer performance expectations and mileage regulations depend on electronic technology for their intelligent functions.** For this reason, many developing countries have based their future plans on developing strong electronics capability to underlie broad industrial development.

The United States, inventor and leader in electronics for most of the post-war era, came to depend, for one of its primary competitive advantages, upon electronics sophistication to design and produce goods which out-performed counterparts made abroad. In addition, U.S. military strategy has been based on fewer soldiers, ships and aircraft, endowed with superior fire power by complex electronic weapons systems.

In fact, **commercial developments in most electronics technologies, lead the military state-of-the-art**, although certain special military needs have forced the continuation of an extensive, specialized military electronics development investment program. Microprocessors used in some leading edge personal computers have performance well beyond those embedded in military systems.

As recently as ten years ago, the U.S. electronics industry was hailed as a prime example of a growth industry driven by free market dynamics. Rugged individualism was the management style, as each succeeding generation of technology gave rise to a new cohort of leading competitors. Little cooperation existed among firms competing in an unregulated marketplace and governmental involvement in most parts of the industry was minimal. The base of electronics suppliers was highly fragmented; new firms continually appeared to exploit new product and technology concepts. Older, larger, established firms often found themselves at a disadvantage in fielding timely new products to compete with these faster-moving start-up concerns. Many founders of these new enterprises were recent employees of these same larger firms, with knowledge of the firms' research results.

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[1] 1989 U.S. Industrial Outlook, U.S. Department of Commerce, International Trade Administration

[2] A Strategic Industry at Risk: A Report to the President and Congress from the National Advisory Committee on Semiconductors, November, 1989, page 5

[3] Dataquest, Stanley Bruderlie, private communication

During the past decade, this picture has changed. New computer and semiconductor enterprises continue to be established, but many smaller firms now find that they cannot mount the global, sustained presence necessary to succeed in the world market and that financial pressures for quick return force them to compromise longer term development goals. In addition, the highly cyclical electronics business takes its toll on small, thinly-financed enterprises. Larger U.S. firms are discovering that they face determined competitors from abroad, many of whom reside in protected markets, and are well supplied with less expensive, more patient capital.

The electronics hardware market is, for the most part, global. Only national content regulations and purchasing practices limit access to local markets. Small size, low weight, and high value make electronic systems, subsystems and components readily transportable. Identical component technology is widely used; for instance, components used in communication equipment are essentially universal, although operating standards vary from country to country. Television receivers made for American and European markets employ different broadcast standards, yet their components are very much alike. Hence, **electronics competition for many sectors takes place on a worldwide scale, and major electronics suppliers operate on a multinational basis.** It is common for vendors headquartered in one country to manufacture components in a second country, to supply to equipment manufacturers in a third country, and for the finished electronic products to be sold to users in still a fourth nation.

Electronics technology is both rapidly changing and quickly communicated around the globe. Several factors, including national government industrial policies, the open U.S. technical education system, mobility of skilled technical professionals, globally distributed U.S. manufacturing and purchasing practices, and developing nations' determination to do whatever is necessary to succeed have helped to develop the technical infrastructure needed to support effective, non-U.S.-based competitors.

A world market, once served primarily by U.S.-based electronics producers, is shifting to a more distributed supply base with Asian and European firms having large, in some cases dominant, production shares. The technology, invented and first reduced to practice in the United States is becoming highly dispersed. U.S. manufacturers, residing in an open market, are finding important parts of the world customer base denied to them, but available to competing firms.

Much of electronics technology has become extremely sophisticated, requiring long-term, major R&D and capital investments to keep up with the leading edge pace. In addition, the electronics industry has long held that production excellence, as measured by cost, quality and product function, is strongly driven by volume production experience. Lessons learned by leading producers in the global market accumulate to form barriers to less experienced competitors.

Structure

The electronics industry is generally thought of in terms of its Original Equipment Manufacturer (OEM) product segments: Computers, Telecommunications Equipment, Consumer Electronics, Industrial Electronics and Instrumentation, Transportation Equipment and

Government (Military) Electronics. In fact, the industry's structure is more complex. A schematic representation of this structure is shown in Figure 1.

In the United States, companies participating at each level of the industry structure are, for the most part, autonomous. OEM firms (with the exception of a very few "captive" producers) rely upon components purchased from outside the company. Semiconductor manufacturers do not generally make their own processing chemicals, raw materials or manufacturing equipment. **Reliance of each level of the electronics industry upon upstream suppliers for important equipment performance features and enabling technology, and the complexity of the technology makes the inter-level ties and close vendor-customer cooperation more critical to success in the electronics industry than elsewhere.**

As semiconductor technology has advanced, OEMs have embedded more and more hardware capability in very complex integrated circuits. The performance of a personal computer depends implicitly upon the characteristics of the complex microprocessor and memory "chips" employed. The speed of a mainframe computer depends, to a large extent, upon the speed of the logic elements used. OEM equipment performance can depend as well on non-semiconductor components, such as heads for magnetic tapes and disks, magnetrons for microwave ovens, crystals and ceramic filters for communications equipment and large area displays for television sets and computers.

In the same way, semiconductor manufacturers rely upon their materials and equipment suppliers who develop important fabrication processes and materials technology in addition to providing raw materials and machines; ability to fabricate sub-micron integrated circuits hinges on the availability of suitable lithography and etch equipment and resists.

If the chain of reliance of downstream electronics product sectors on upstream suppliers is jeopardized (for instance by unavailability of state-of-the-art components), the competitive capability of the entire structure is at risk.

Firms at each level operate so as to optimize their individual financial return, rather than the economic performance of the overall structure. This vertically disintegrated industry system tends to develop problems in the working relationships at the interfaces between levels. **Effective management of an electronics effort requiring shared risk at the OEM, component and materials levels to achieve the best overall result is rare.**

To paraphrase Churchill, "Rarely have so many been so dependent on so few." As a result of an independent tradition, American upstream firms tend to be smaller than their downstream customers. Thus, the U.S. electronics industry structure is shaped much like an inverted pyramid standing on its tip, as in Figure 2.

The U.S. picture stands in sharp contrast to the structure of the electronics industries in Japan and Europe. **Participants at each level of the vertically disintegrated U.S. electronics industry face large, well-financed, diversified industrial firms whose extended family of companies often include OEM business, component manufacturing, raw materials supply, and manufacturing equipment production capability.**

Japan's Sumitomo Group is one example. Nippon Electric Corporation (NEC), a Sumitomo company, is a diversified, Japanese manufacturer of telecommunications equipment and computers. In addition, NEC has an active consumer electronics business. NEC is also the world's leading semiconductor producer which buys most of its raw materials from other, specialized Sumitomo companies. NEC's annual electronics business amounts to more than $24B, part of the Sumitomo Group's total $230B annual revenues.

The world's ten largest electronics firms are identified in Table I. Note that of the top ten, five are Japanese, two European and three U.S. concerns.

OEM Segments

Table II shows world OEM electronics production. In the United States, the industrial and computer segments are proportionately larger production sectors; abroad, consumer electronics is proportionately bigger.

The primary hardware technical skills of OEM producers lie in discrete assembly manufacturing, system integration, and product field support.

Traditionally, computer, military, instrument and industrial electronic equipment employed the most sophisticated technology, and consumer products were simpler, made to be manufactured cheaply, in high volume. This is no longer the case -- some consumer technologies are well ahead of those in other areas.

As Table II shows, OEM firms based in the United States continue to maintain world production leadership in many lower manufacturing unit volume segments such as computers, industrial electronics and instrumentation, telecommunications equipment and military electronics. Their Japanese and European competitors, on the other hand place much greater emphasis on consumer electronics. American leadership, however, is steadily eroding as foreign competitors have turned their focus on computer and telecommunications segments and have sought to apply lessons learned from the consumer electronics business. U.S. firms, however, continue to maintain world leadership in systems-related technologies, certain computer peripheral products such as disk drives, instrumentation and computer architecture.

Mass production requirements of video tape recorders, videocam CCD chips, flat screen Tvs, talking toys and digital audio disk players have raised the level of design, process, tooling and materials technology and manufacturing practice used in consumer products to a par with that used in other electronic segments. Furthermore, the manufacturing techniques developed to economically mass produce such high technology components as video tape heads, large area liquid crystal displays for lap-top computers, print heads for FAX machines and digital audio disk lasers go well beyond those required for traditionally "sophisticated", but lower production volume, businesses.

The United States lost its leading position in consumer electronics to the Japanese and other Asians in the 1970's. Figure 3 shows the import percentage of the U.S. consumer electronics market for the past 15 years. The television and audio entertainment portion of consumer electronics has been particularly hard hit. A majority of TV sets sold in the U.S. are imported, and most of the sets manufactured on-shore are produced by foreign-owned firms. Only a single U.S.-owned television receiver manufacturer remains -- Zenith.

Europe has managed to hold onto its consumer electronics industry through concerted private and governmental effort. The result has been that Japanese-, Korean-, French-, West German- and Dutch-based companies have benefitted most from the revolution in consumer goods.

The loss of the consumer electronics industry has severely undermined the manufacturing technology base of the U.S. electronics industry as a whole. Consumer electronics manufacturing methods have now become important in the computer, industrial and telecommunication segments, as products such as personal computers, FAX machines, videocams and cellular telephones have become popular. In each of these cases, lessons learned from manufacturing inexpensive, high quality, high performance consumer products are carrying over to other OEM sectors.

Furthermore, driven by changes in the consumer field, new product life cycle times have significantly decreased. Formerly, electronic product companies could develop products one at a time, turning to new generations only after existing products were introduced to the market and selling well. **Now several product generations must be developed at any one time, and speedy, error-free product realization is an important factor in market leadership.** Concurrent development is replacing sequential methods.

Deterioration of the relative ability of American companies to serve their home market is evident in all OEM segments. Figure 4 shows the import percentage of the U.S. electronics market for principal non-consumer OEM sectors.

One other important characteristic differentiates Japanese electronic firms from those in the United States and Europe. **Japanese-based OEM businesses strongly prefer to buy from related Japanese-based suppliers. U.S. and European manufacturers are much more prone to select suppliers based on price and availability, whatever their nationality or affiliation.**

Component Businesses

The semiconductor portion of component level businesses receives by far the most attention because of the close relationship between integrated circuits and OEM product functions. Other component businesses, however, also have an important effect on finished product cost, quality and performance. Without displays, keyboards, resistors, capacitors, coils, batteries, crystals, printed circuit boards and connectors, OEM products cannot function.

Approximately one-third of all OEM hardware income is spent on components. And approximately one-third of component costs are semiconductors. The semiconductor fraction of the component business has been increasing because complex, VLSI integrated circuits incorporate an increasing portion of OEM product electronic functions. The overall component percent of OEM hardware income, however, has remained substantially flat, limited by costs that OEMs can bear, since per-function integrated circuit costs have fallen as chip complexity has increased.

In addition, components such as displays, keyboards and batteries have a significant impact on the form and function of many electronic products. Thus the ability to effectively use leadership component technology is an important element of leadership at the equipment level of the industry.

The import share of the U.S. components and semiconductor markets is shown in Figure 5. Note that the same loss of U.S. production share trend is evident for both semiconductor and non-semiconductor components.

The semiconductor industry is the largest component segment; many factors which affect it also affect other components businesses. Semiconductor industry statistics are the best developed and the following semiconductor discussion is intended to illustrate overall component industry trends.

The world's largest semiconductor suppliers are listed in Table III, and the world production share history of U.S., Japanese and European producers in Figure 6.

The decline of U.S. producer share stems mainly from two factors: loss of the consumer electronics customer base, and competitive problems with memory products.

The first market share dip, which occurred in the late 1970's resulted from loss of U.S. control of its consumer electronics manufacturing base -- the largest unit volume user of semiconductor products. As U.S. OEM consumer electronics firms were sold to Japanese buyers, their semiconductor requirements were shifted to Japanese semiconductor producers as the volume of Japanese-designed TV sets and home audio entertainment products replaced that of older U.S. units. **Thus U.S. semiconductor manufacturers watched as important customers virtually melted away.** Faced with the loss of customer base, U.S. merchant market producers significantly reduced their consumer entertainment component efforts, remaining primarily in specialized niches, such as automobile radio circuits.

The more recent, sustained loss of semiconductor market share is a result of difficulties of the U.S. industry in competing against Japanese competitors in important, high volume commodity semiconductor products such as memories and discrete products. Figures 7 and 8 show the market share history of these two key product categories.

U.S. semiconductor firms, however, continue to maintain a strong lead in "high-end" (8-bit and above) microprocessors. Japanese producers have clear strength in "low-end" (4-bit) controllers used in consumer applications.

Semiconductor manufacturing is much more capital intensive than OEM equipment production. The semiconductor industry is among the leaders in U.S. industrial sectors in percent of sales invested in R&D. Relative investments in R&D and capital expansion for the top five U.S. and Japanese firms are shown in Figures 9 and 10. Because semiconductor development and OEM equipment design often take place in series, semiconductor R&D takes much longer to pay off. Further, the cost of a modern wafer fabrication production line now exceeds $200 million. It now takes more than $1 of fixed capital investment to produce $1 of annual semiconductor sales; the useful life of that investment is approximately five years. **With this high level of fixed investment, and the long time to payoff, large market fluctuations (which are common in the semiconductor business) produce frequent interruptions of profit flow and the ability to maintain a consistent rate of investment. This is much more of a problem for U.S. stand-alone merchant market producers than their vertically integrated Asian and European opponents.** Such vertically integrated electronics companies are more willing to cross-subsidize components operations to achieve distinctive OEM equipment features and performance.

Investments of this size require ability to compete throughout the world. Japanese, American and European firms compete on an equal footing in the North American and in many areas, European markets. European and American-based firms, however still face major barriers in the Japanese market. In spite of 20 years of consistent marketing, manufacturing and development investment in Japan by leading American firms, and major efforts to sell semiconductor products in Japan, the U.S. share of the Japanese market is still disproportionately small. Figure 11 shows the relative market share of U.S. and Japanese producers in each others' home markets.

Unlike the Japanese industry, where participants are very large, many U.S. semiconductor firms are modest in sales: in 1988, 52% of U.S. semiconductor companies had sales less than $100M, and 88% less than $500M.[4] As Table III shows, only three U.S. suppliers had more than $2B in sales versus five Japanese.

The Japanese semiconductor demand amounts to about 40% of the total world market. **Given current patterns of world trade, to the extent that Japanese firms have preferential access to their own market, they have nearly twice the worldwide opportunity to earn a return on their fixed capital and R&D investments than do competing American firms.** In view of the tendency for Japanese off-shore plants to procure their components from Japanese suppliers, their advantage may be even greater.

The access problem, in the case of Japanese companies is more a matter of company purchasing and design practices than it is a case of governmental restrictive controls.

The technology of component manufacturing differs from that of OEM electronic product manufacturing. OEM production is generally "discrete" manufacturing -- the assembly of components and subsystems into complete products -- and system integration -- engineering the interfaces between system elements. Component production, on the other hand, tends to be electronic device-, circuit-, chemical processing- or materials-based. In some respects, component companies are more like chemical processing or materials firms than they are like their OEM customers. Many technical skills and financial standards that apply to OEM businesses differ from those of the components sector. **In the United States, this difference limits the extent to which the component and OEM levels in U.S.industry can assume each others' function.** Each level requires different competences and measures of success. Even in vertically integrated U.S. companies, technical personnel from component and equipment operations are not readily interchangeable for skill reasons. Many large OEM corporations have attempted to enter the broad-based merchant market semiconductor business, but have not succeeded: GE, Westinghouse, Ford, GM, Sylvania, Honeywell and Hughes are examples. Work force availability is usually not the problem -- the American labor force is very mobile -- the issue is leadership ability to depart from previous OEM electronics management practices and embrace businesses with quite different characteristics. Large diversified company groups, such as those found in Japan and sometimes in Europe, however, frequently do possess the range of skills and financial flexibility needed to bridge this competence gap, or are willing to take time to develop expertise internally, given stable employee populations.

The semiconductor business differs in one major respect from the rest of the electronic components industry. The evolution of complex VLSI integrated circuits has compelled OEM manufacturers to embed increasing amounts of their product electronic function in integrated circuits. The unique requirements of each product application frequently demand that complex integrated circuits be designed for a specific use. **Thus, a portion of the semiconductor industry is moving away from the commodity product approach characteristic of other component segments, and moving toward application-specific integrated circuits (ASICs).** This shift demands new skills of the integrated circuit manufacturer, as ASIC products have smaller manufacturing volume and greater variety than do traditional "standard" (commodity) products. The working relationship between OEM user and ASIC maker must be unusually close and carefully defined. Emphasis in this portion of the semiconductor industry is on service, and flexible manufacturing -- something that long-time industry leaders are having trouble grasping, regardless of national origin. To the extent that American producers can master the ASIC business, it offers an opportunity to build closer relationships to U.S. OEM customers.

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[4] Changing Customer Requirements: A Force for Change in the Semiconductor Materials and Equipment Industry, Talk delivered by William F. Finan to the 1989 Information Services Seminar, January, 1990

Many of the manufacturing skills required to succeed in the ASIC business -- one which is based on manufacturing small unit volumes of a large variety of products -- differ from those required for success in commodity semiconductor products. Leading U.S. ASIC competitors are new firms, established specifically to compete with CMOS products - the largest technology market. Larger, more established U.S. and Japanese semiconductor firms have so far been unable to compete effectively in this newest segment of the component business, although they are continuing to invest in the ASIC business.

Other components, especially advanced displays, are critical to OEM equipment strength. Advanced displays are flat-panel alternatives to bulky cathode-ray tube (CRT) displays. Several technology alternatives are important: liquid-crystal, vacuum florescent, plasma, electrolumimescent, and light-emitting displays. The 1989 world market for these flat-panel products was $3.2B, and is expected to grow at a 20%/year rate through the 1990's.[5] These products will have a major effect on portable computer, communications and consumer electronic products.

In each technology, there are significant hurdles to be overcome. While much of the advanced display technology base is of U.S. origin, Japanese firms have much greater accumulated manufacturing experience.

Electronic Materials and Manufacturing Equipment

The materials and manufacturing equipment (ME) businesses form the most vulnerable portion of the electronics industry structure. These businesses are highly cyclical, since they are last to feel the effect of electronics industry fluctuations, which occur rapidly and unpredictably. Unfortunately, the magnitude of these fluctuations are huge, as they reflect all the inventory slack of the two downstream levels. Typically, materials and manufacturing equipment businesses are either saturated with orders, well beyond their ability to supply, or have no orders whatsoever.

Virtually all large U.S. firms have left the merchant market semiconductor materials and manufacturing equipment business. Companies such as Monsanto, Coors, Dow, Union Carbide, GE, Motorola and, most recently, Perkin-Elmer all found that these businesses were not to their liking, mainly because of the highly cyclical nature of these businesses. The remaining U.S. participants are smaller, single product line firms who are now pitted against giant foreign-based competitors. Their position in the market is weakening, as shown by the product ranking data in Table IV. As Figure 12 shows, more than 80% of U.S. semiconductor materials and equipment production is by firms with sales of less than $25 million.

Basic skill of materials and fabrication equipment makers generally lie in the process physics and equipment design and manufacturing. The technical sophistication of these products is not to be underestimated. Submicron device capability begins with development of optical, electron-beam or x-ray lithography tools, patterning resists and reactive ion etch equipment.

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[5] Source: Stanford Resources, Inc.

Before such equipment and materials can be developed, a great deal of basic process research must be successfully completed. Such development is frequently a joint effort between individual semiconductor component firms and their equipment suppliers. The results of such joint efforts are generally embedded into the equipment or material and offered for subsequent industry-wide sale. Materials and equipment firms provide important support across the industry, since process information accompanies the sale of raw materials and fabrication equipment.

The timeliness and quality of the materials and equipment supply connection is thus critical to semiconductor competitiveness.

Although fabrication equipment requires similar system integration skills to those present in OEM-level electronics firms, fabrication firms are having difficulty with them. SEMATECH reports that 30% of semiconductor fabrication equipment introduction failures are the result of software problems.

Twenty-five years ago, some semiconductor device producers developed and produced their own fabrication and test equipment, reasoning that unique equipment formed the basis for distinctive manufacturing competence. Each found, however, that the needs of a single firm were insufficient to justify the investment required to mount an equipment development operation, and dropped most of these activities in the mid-1970's.

Lack of a single, industry-wide specification for equipment form fit and function is part of the problem faced by semiconductor fabrication and test equipment manufacturers. Each supplier must custom tailor its capital equipment products to meet unique customer needs. Effort is lost in duplicate development of electrical and mechanical interfaces. The same economy of scale requirement that caused the device companies to drop equipment development activities is a problem for current M&E suppliers.

The U.S. material supply base is in particularly bad shape. No major suppliers of semiconductor-grade silicon remain under U.S.-based control and Japanese firms dominate the ceramic package parts, glass mask blank, gallium arsenide materials and many other essential semiconductor materials supply businesses.[6]

The foregoing discussion has centered on semiconductor materials and equipment supply. The same concerns are reflected in other electronics M&E areas. For instance, the domination of Japanese pick and place equipment for printed circuit board assembly and loss of a U.S.-based passive component supply base parallels that seen in semiconductor materials and production equipment cases.

Challenges Facing the Electronics Industry

Firms in the U.S. electronics industry, regardless of level, face a number of common challenges. These challenges are not new, but are becoming increasingly serious with the passage of time. **Industry data show that, regardless of level, the U.S. electronics industry is losing its world leadership.** In some cases, such as the consumer electronics and materials fields, there is little U.S. industry base left to be challenged -- control resides primarily abroad. In a number of OEM segments, such as computers, instrumentation and telecommunications, American competitors remain in strong positions, but are increasingly threatened. Much the same holds for the microprocessor portion of the semiconductor business.

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[6] op cit: A Strategic Industry at Risk, p. 15

General Challenges: Vertical Structure

A serious weakness of the U.S. electronics industry structure is its lack of vertical integration which allows risk and opportunity sharing between levels in the interest of producing overall strength. To be successful, such a framework must encompass a relationship between vendor and customer that transcends simply purchase price and delivery, and allows for a more extensive give-and-take relationship in the vigorous pursuit of long term mutual prosperity.

As indicated above, history shows that vertical integration within a single, traditional U.S. corporation has not generally been an effective way of addressing vertical structure. Recently SEMATECH, the semiconductor manufacturing consortium, has focussed much of its effort on building a more effective relationship between semiconductor manufacturers and fabrication equipment makers. Other attempts to establish pooled user groups to ameliorate weaknesses in critical electronics materials and semiconductor fabrication equipment companies have produced mixed results.[7]

Nevertheless, the electronics industry faces the challenge of experimenting with new relationships between customer and vendor to establish workable vertical ties.

Capital

Cost and patience of capital is a serious problem throughout the electronics industry. In view of the capital intensity, particularly in the semiconductor component, materials and equipment sectors, the financial burden on U.S. firms of competing at each level of the structure against foreign competitors who can work for long term, overall gains, and who bear significantly lower financing costs is onerous. The effect of this on management options is substantial and well known.[8] **The type of short-term management thinking forced by the current financial environment jeopardizes not only capital expansion and R&D activities at all levels of the industry, it imperils the very existence of the small firms that provide much of industry's base.**

The differential cost of capital faced by electronics producers in the United States and Japan also makes many U.S. electronics firms and the technologies they practice attractive purchase candidates at all levels of the electronics industry structure.

Product Cycle

New product development is an important source of renewal for businesses. The learning that accompanies development and introduction of new products as well as the products themselves helps to make obsolete less advanced competing businesses.[9] Companies that are faster and error-free at producing new products tend to build up a substantial lead over competitors that are slow reach the market.

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[7] "Investors' Yen for U.S. Technology", Science, December 8, 1989, pp 1238-1241. The companies involved were Materials Research Corporation (MRC), and Monsanto's electronic silicon supply operation. Perkin-Elmer and U.S. Memories may be other examples.

[8] Hatsapoulos, George N., Paul R. Krugman, Lawrence H. Summers, "U.S. Competitiveness: Beyond the Trade Deficit", Science, July 15, 1988, pp. 299 - 307

Especially in the consumer electronics field, American electronics companies are well behind the Japanese in their ability to design and field attractive products with new features and designs. United States failure to keep up with the pace of development of new dynamic RAMs and to produce complex new products that were free from design defects was a factor in America's loss of the memory chip market.

A shorter product development cycle must become a priority throughout the U.S. electronics industry if it is to keep up with competition. This entails a strong push for new methods of concurrent development, and investment in computer-based tools that can speed design task while reducing errors in ever more complex designs. Although more elaborate design hardware may help reduce product design cycles, the biggest gains to be made are in organization and management of the product and manufacturing process development activity to stress timely, error-free products.

Consumer Electronics

The seriousness of the loss of U.S. viability in the consumer electronics segment was not appreciated at the time it happened, inspite of expressions of concern by companies, labor and individuals in the industry. The effects of this loss go well beyond the immediate loss of the sales.[10]

In retreating from consumer electronics, U.S. manufacturers who otherwise would have been forced to tackle the problems of volume production and new consumer technologies, turned their attention elsewhere. The ripple effect of the loss of volume component and materials markets extended vertically and laterally through electronics industry, including the components and materials and manufacturing equipment structure, to affect the volume of production and pace of technical advance at all levels.

The U.S. electronics industry is now faced with the daunting challenge of either competing to win the consumer electronics industry back from Asian producers, or coming up with a substitute volume production base with which to hone mass production skills. Neither option has promising prospects. The consumer electronics business is securely in the hands of competent, established, foreign firms, and past attempts to find products with a sustained U.S. high volume production base have been short-lived (e.g., electronic games, calculators, CB radios, watches).

Market Access

Japan is a world-class market in the sense that Japanese electronics customers at all levels of the structure demand perfect performance. Ability to compete successfully in this toughest of business environments implies the ability to succeed anywhere else. The potent stimulus of driving to serve such critical customers helps firms identify and solve chronic operational and technical problems.

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[9] Gomory, Ralph E., "Turning Ideas into Products", The Bridge, vol. 18, No. 1, Spring, 1988, pp. 11 - 14

[10] op cit: A Strategic Industry at Risk, p. 17

As indicated above, inability of American firms to gain access to market abroad (especially in Japan) not only provides foreign competitors a safe haven for development of new products and technology, it greatly reduces the opportunity U.S. firms have to build manufacturing volume and to earn a competitive return on capital and R&D investments. Electronics competitors from abroad have much fewer restrictions on selling in the United States. Leading U.S. electronics companies have demonstrated a sustained, strong commitment to selling, producing and developing electronics products within Japan. They have received awards from their Japanese customers for on-time performance, and high quality and are price competitive, and yet still do not gain share of market. Recently, U.S. companies have begun trading their leadership technology in return for market access in partnership arrangements with Japanese competitors.

Ways must be found to participate effectively in major electronics markets around the world so that U.S. producers have the same chance for global leadership as competitors from other nations.

Quality

Quality has become a more visible factor in electronics as a result of significant progress made by Japanese suppliers over the past twenty years. Customer product quality expectations and the level of quality required by today's complex production processes go well beyond much of the American electronics industry's experience. In addition, we tend to undervalue the importance of small, but continuing, improvements.

The element of the American character that appears as impatience to "get on the to next task" manifests itself in a relative reluctance of many Americans to pay attention to the kinds of details, in all phases of a business, that make for error-free performance.

Attention to detail is particularly important in fields such as electronics where several complex technologies each must come together to make products work as designed. Complete understanding of each aspect of design and fabrication of components as well as complete systems is essential to ensure best possible quality and reliability.

Anyone experienced in the American semiconductor industry who visits Japanese plants can't help but be impressed with the completeness of process and design characterization. Process reliability data and control information collection is carried to a level that would frustrate many American engineers and technicians. The result for Japanese producers, however, is a product which reaches the market in "bullet-proof" form -- free of initial design and manufacturing defects. In contrast, American equivalent products are often rushed to the market with bugs remaining in design and production processes -- bugs which take time and customer frustration to work out.

While U.S. manufacturers have significantly improve the quality of their products and operations over the past decades, more remains to be done. In order to be competitive, U.S. **electronics companies must find further ways to assure that new and on-going products are subject to the same level of scrutiny at all levels of company operations as in the world's best suppliers.**

Technical and Production Skills

Technical and production knowledge and skill are essential ingredients of success in "high tech" industries. As the largest of these industries, electronics has the most critical demand for professional and paraprofessional skills. In addition, as automation becomes pervasive in factories, operators, who once needed only the most rudimentary literacy skills, are assuming many of the responsibilities for technical support. Leading companies have found it necessary to reeducate many of their production people in technical literacy and numerical skills in order for them to satisfactorily perform their jobs. Robert Galvin, former chairman of Motorola, estimates his company's investment in training to equal its R&D costs.

In addition, the sustained rapid rate of change of electronics technology demands continual retraining of professional and technical personnel to keep abreast of new developments.

Finally, modern manufacturing methods require new skills (such as statistical process control) and group approaches to problem solving that are unfamiliar to the current work force. These challenges must be met by still more training.

Traditionally, American culture places the responsibility for training and education mainly on the school system and, later, on the individual. Neither of these mechanisms will be able to produce the competence level and number of graduates needed to assure that American companies have the quality and quantity of skilled people here at home to assure competitiveness.[11]

The electronics industry must become more engaged in the educational process if it is to maintain a work force with skills commensurate with future technical need. This engagement means effective internal training activities as well as working with local and national institutions.

Managing the Changing R&D Structure

The cost of continuing internal R&D activities at the leading edge of electronics technologies places a heavy burden on each level of the electronics industry's structure, particularly in the absence of effective industry vertical structure. The reaction of many electronics concerns to these increasing costs has been to draw in the time horizon of internal new technology activities. In addition, they have increasingly begun to rely upon external sources for new technology for future products and processes. The result has been increasing reliance on shared development activities, such as university-industry, government-industry, consortia and joint venture activities, for some new technologies.

In many cases, experiences of companies in these shared development efforts has not been good. Conflicting partner interests, problems with technology transfer and failure to understand the ability of the various parties to contribute have all lessened the effectiveness of many shared development enterprises.

Shared R&D is a necessity of doing business in fields where the cost of developing new technology is as high as it is in some electronics instances. Learning how to manage such joint activities for the benefit of the participants is a challenge if the electronics industry is to

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[11] Focus on the Future: A National Action Plan for Career-long Education for Engineers, National Academy of Engineering, 1988 pp. 42-43

continue to take advantage of joint technology development mechanisms to reduce R&D costs for individual companies.

Technical Challenges

Several critical technical challenges confront electronics manufacturers:

1. Sub-micron Technology

Description:

Sub-micron technology is the combination of device and processing technology needed to make integrated circuit devices with critical dimensions of 0.5 micron or less. It includes design and structure of ultra-small devices, including short-channel considerations, surface and interface effects, contact and metallization technology, as well as patterning, materials deposition, substrate materials and interconnection metallurgy. Integration of all these process elements into a complete process flow is a critical aspect of the technology.

Why is this a Critical Technology?

Sub-micron technology is the continuation of the mainstream of silicon integrated circuit technology. Improvements in circuit density, logic speed and power dissipation that have driven memory and microprocessor developments have all arisen out of technology developments preceding the sub-micron level. Leadership in the mainstream of semiconductor electronic products depends upon mastery submicron technology.

U.S. Position with Respect to the Rest of the World

U.S. researchers have developed many of the basic elements of sub-micron technology; Bell Laboratories and IBM did some of the earliest experimental work in sub-half micron devices. However, Japanese merchant market semiconductor producers have put in place longer-range technology development programs to make sub-micron technology producible in mass production. The focus of Japanese semiconductor firms on commodity memory products has provided both the production experience to establish a base of advanced manufacturing knowledge, and the technology "driver" around which to develop sub-micron technology. While Japanese lead, European and other Asian commercial semiconductor producers lag U.S. merchant market and captive semiconductor producers in sub-micron technology.

Factors Enhancing U.S. Competitiveness

The emphasis of the U.S. electronics equipment business lies at the high performance end of the spectrum in computers, industrial, military and telecommunications products. The need for integrated circuits employing sub-micron technology will normally occur first in these sectors, making the United States the largest immediate market. The Department of Defense Very High Speed Integrated Circuit (VHSIC) program gave some U.S. merchant market companies early experience at the 0.5 micron device technology level, but slow diffusion of this technology into commercial applications, in part due to military export restrictions, limited the value of this experience.

SEMATECH, the semiconductor industry/DoD consortium, is planning to work on production aspects of sub-micron technology, but has not yet begun major efforts in this area.

Factors Detracting from U.S. Competitiveness

Japan's vertically integrated electronics enterprises are keenly aware of the importance of sub-micron technology's importance to their OEM equipment future. With governmental support, they are developing sub-micron technology on a high priority basis.

Sub-micron technology requires advances across the entire range of semiconductor electronics technology. Materials, fabrication processes, fabrication equipment, process integration, device structures and applications developments are needed before sub-micron technology can become a production reality. The United States lacks strength in some of the areas required for this development (notably, materials production and sub-micron lithographic tools) and the vertical coordination between materials, fabrication equipment, semiconductor producers and OEM users is less effective than in Japan.

The Joint European Sub-micron Silicon Initiative (JESSI) supported by the EEC, is an attempt to develop a strong, multi-company sub-micron technology base in Europe. The effectiveness of JESSI, however, has yet to be demonstrated.

Technological Dependencies

Sub-micron technology development depends upon a close coordination of developments in a number of supporting technologies, such as materials, process development, production equipment development, and clean-room technology. In turn, leadership in high performance OEM equipment sectors such as supercomputers depends on a reliable source of leading edge components. The technical dependencies between the various firms involved in each of these technologies is stronger than their business connections.

As the main stream semiconductor technology, access to nanofabricated devices is important to achieving hardware performance leadership in a wide range of OEM equipment areas.

2. Optoelectronics Technology

Description

Optoelectronics technology consists of the devices, packaging and interconnection means for transmission or processing of information in optical, rather than electrical form, with electrical interfaces. Optical sensor and laser devices, optical fibers, integrated optical devices, and optical information processing are included in the optoelectronics field.

Why is this Technology Important?

The ability of optical communication channels and processors to quickly deal with large amounts of information can be much greater than that of electronic counterparts. For instance, fiber optic communications circuits have bandwidths of several gigaHertz, as opposed to electrical cable and microwave capabilities measured in 10's or 100's of MegaHertz. Predictions have been made of similar improvements in special purpose computers based on optical processing.

Optoelectronics is already a major factor in military, precision measurement, telecommunications and consumer products. It is a likely long-range future choice to replace some high performance electronic computer functions.

U.S. Position with Respect to the Rest of the World

Strong military interest in special sensor and laser developments, such as focal plane arrays, has given the United States a lead in those specific areas. In addition, the U.S. level of device and fiber technology for telecommunications equipment is as advanced as that of any other country. The Japanese state of the art is comparable. However, Japanese experience in applying and producing in volume lasers and sensors for consumer and telecommunications purposes has given greater production experience in making low-cost, reliable lasers and detectors.

European optoelectronic technology generally lags that of both the United States and Japan.

Factors Enhancing U.S. Competitiveness

Strong military interest in the optoelectronics field makes this a logical one for DoD support. In addition, past DoD investments have supported a strong device research capability in academia and military contractors.

The U.S. technology base in engineered materials research (needed for state-of-the-art optoelectronic devices), using molecular beam epitaxy (MBE), is particularly strong. In addition, strong long-term support from telecommunications and glass materials suppliers has resulted in strong U.S. optoelectronic device and fiber capabilities.

Factors Detracting from U.S. Competitiveness

Aside from telecommunications, instrumentation and military applications, U.S. OEM equipment producers have been slow to apply optoelectronical technology Consumer electronics applications such as compact disks, videocams and copier print heads have provided the opportunity for Japanese firms to perfect high volume production skills.

In the engineered materials area, the Japanese have concentrated on developing chemical vapor deposition technology -- one which is better suited for volume production of complex engineered materials than MBE.

In addition, much of the compound semiconductor materials base that supplies optoelectronic device manufacturers resides in Japan.

Technology Dependencies

The materials and fabrication technologies used for optoelectronic devices is very close to that needed for high performance electronic compound semiconductor devices, such as gallium arsenide microwave transistors.

3. Integratd Circuit Fabrication Equipment

Description

IC fabrication equipment technology includes production equipment for substrate wafers, lithography, etching, doping, materials deposition, package assembly and electrical and physical testing. Fabrication equipment technology is intimately connected to semiconductor process technology (such as the characteristics of U-V photoresists in the case of lithography, ~~and~~ particle elimination for all equipment types), as well as technology required for operation of the equipment (lenses and precision positioning technology for photo-steppers) and computer controls.

Why is this Technology Important?

Much of the process technology required to produce electronic component products is imbedded in fabrication equipment. For instance, ability to make sub-micron integrated circuits is intimately tied to the lithographic tools used, as well as etching equipment employed. Component manufacturers are therefore critically dependent upon the capability of the tools available to them.

U.S. Position with Respect to the Rest of the World

The early U.S. lead in IC fabrication equipment technology (for instance, the initial producers of step and repeat cameras, dry etchers, computer-driven testers, and plasma deposition reactors were American), has substantially eroded. The United States retains the lead in ion implantation and some types of plasma materials deposition, but has lost the lead in photolithographic tools, vacuum deposition equipment and substrate materials production equipment. The tester and packaging assembly businesses are still close contests between U.S. and Japanese suppliers.

Most of IC fabrication equipment competition has come from Japanese firms related to Japanese component makers.

Factors Enhancing U.S. Competitiveness

Much of the new technology application in the IC fabrication equipment field takes place within small equipment companies working together with their components-producing customers. Nearly 90% of U.S. IC fabrication equipment makers have sales of less than $25M. The United States has provided a fertile environment for such start-up companies, whereas the formation of high technology new ventures is much less prevalent in either Europe or Japan.

Factors Detracting from U.S. Competitiveness

A strong factor in favor of Japanese IC fabrication equipment technology is the close relationship between most of their fabrication equipment suppliers and their components production customers. The close relationship between Toshiba and Nikon was a major factor in the latter company's eventual success in the photo-stepper business. Similar relationships between Ando and Anelva with NEC has contributed to their strength in the integrated circuit tester and vacuum deposition fields. Similar close ties between U.S. fabrication equipment and component firms are awkward in the United States.

The small firms that are the U.S. strength in fielding new fabrication equipment technologies have a corresponding weakness. Many such small firms lack the resources and staying power to be successful in the world market in the long run. As they run into trouble (often financial) they become attractive take-over targets -- often for Japanese companies. The eventual outcome is frequently loss of U.S. control of the firm's technology (e.g., the purchase of MRC by Sony and a 15% share of LTX by Sumitomo).

Technological Dependencies

Production capability, yield and product quality and reliability are strongly related to production equipment. U.S. component manufacturers have noted that they are often unable to buy the latest production equipment from Japanese firms who sell to related Japanese customers first. As a larger portion of the fabrication equipment base becomes Japanese, this places U.S. component makers at a continual disadvantage with respect to their Japanese competition.

4. Packaging and Interconnection Technology

Description

Packing and Interconnection refers to technology, from component package to the OEM system level, for protecting, cooling, and conveying signals and power throughout an electronic system. The signals may be electrical or optical or, in the case of sensors, physical.

Important elements of packaging and interconnection technology include packaging materials, fabrication processes and materials engineering, package design, the assembly process, multichip technology, boards and substrates and connectors.

Why is this a Critical Technology?

Packaging and interconnection determine many of the characteristics of high performance electronic equipment. Ability to quickly convey signals throughout an electronic system and to remove heat have a direct bearing on overall system speed. Packaging density and flexibility often limits portable electronic equipment size, form and weight. Development of reliable, cost-effective multichip module packaging technology could have a significant effect on OEM equipment performance, size and weight.

Packaging and interconnection are also critical determinants of cost and reliability of electronic products. Most electronic equipment malfunctions in the field occur as package or interconnection failures and cost of consumer electronic products are dominated by package, interconnection and assembly.

U.S. Position with Respect to the Rest of the World

As the initial developer of solid state electronics, U.S. industry also had to invent related packaging and interconnection technologies. Hermetic and plastic packages for components, printed circuit and hybrid circuit technology for sub-assemblies and connector and back-plane technology for complex equipment all arose together with solid state component capability. The United States set early standards for package and interconnection configurations, construction and reliability evaluation through a series of DoD and U.S. industry standards that became world practice in the 1960's and early 1970's.

European and Japanese companies began to assert leadership in packaging and interconnection in the mid- to late-1970's as they sought technology capable of producing denser, less expensive electronic products. The Europeans led with small-outline and leadless chip carrier concepts, and Japanese developed inexpensive flexible circuit, chip on substrate and multi-chip packages for consumer applications. In many respects, Japanese packaging and interconnection technology is today's world standard for low-cost, performance and reliability.

Factors Enhancing U.S. Competitiveness

U.S. electronics emphasis lies at the high end of the performance spectrum -- in supercomputers, industrial electronics and telecommunications. Properly presented, the needs of these products could be the driving force behind development of package and interconnection technologies that can significantly improve leading edge performance of electronic systems with less investment than that required to develop comparable chip-level technologies.

Factors Detracting from U.S. Competitiveness

Japanese electronics firms have taken the lead in two major aspects of packaging and interconnection technology: They have sought new, denser component packages, both for single and multiple chip applications, which extend beyond existing standard configurations. Many of these configurations are designed to meet specific product needs using computer-aided package design methods. In addition, Japanese consumer electronics product manufacturers (especially Sharp and Seiko) developed low-cost mass-production assembly technologies (including both packaged chip and chip-on-board methods) for their particular products. These techniques are applicable to a broad range of electronics products.

In addition to specific packaging technologies, Japanese companies dominate the supply of certain packaging materials. For both ceramic and plastic encapsulation materials, Japanese materials firms dominate the worldwide market, in both technology and market share.

Technology Dependencies

The effects of packaging and interconnection technology on electronic products is pervasive. Cost, reliability and performance at the OEM product level are very much a result of the packaging and interconnection technology.

5. Electronic Materials Technology

Description

Electronics materials technology covers the entire range of materials comprising electronic components themselves and used in their fabrication. Many of these materials are special in that they must have exceptional physical properties, closely controlled composition, freedom from contaminating particles and defects, or virtually perfect crystalline structure. Electronics materials can be semiconducting substrates, chemical reagents used in chemical processes, photographic mask blanks and resists, packaging materials, or dopant gases. A distinguishing feature of these gaseous, liquid and solid materials is the tight requirements they must satisfy in order to produce electronic components with desired properties, quality and reliability.

Why is this Technology Important?

Electronic materials determine the characteristics of electronic components and costs associated with their manufacture. Ability to gain access to the best possible materials is a necessary precursor to being able to produce competitive, reliable, high quality electronic components.

U.S. Position with Respect to the Rest of the World

The United States has lost its commercial capability to supply a number of important electronic materials. Ceramic packaging piece-parts, photomask glass plates, and gallium arsenide and silicon substrates are now available only from foreign sources or from foreign-owned firms manufacturing in the United States. U.S. sources of supply for gases, photoresist and most reagent chemicals remain competitive.

Factors Enhancing U.S. Competitiveness

The United States has a large and healthy chemical industry capable of producing chemicals to meet electronic material demands.

Factors Detracting from U.S. Competitiveness

The Japanese lead in ceramic and plastic packaging materials is well-entrenched, having been won conclusively and sustained since the late 1970's. More recent attempts to establish American competitive sources of supply have been unable to replace Japanese suppliers as preferred vendors, even with U.S. semiconductor producers.

U.S.-based producers of silicon single-crystal substrate materials have been gradually all been bought out by non-U.S. companies. The most recent companies to sell were Union Carbide and Monsanto, both large, diversified chemical concerns. The failure of these companies to compete successfully in the semiconductor materials field raises serious concerns about the ability of U.S. industry to sustain long-term technology and quality efforts needed to compete effectively with the German and Japanese firms that now lead in this area.

Leading Japanese producers of gallium arsenide substrate materials are related to Japanese companies having equipment applications for gallium arsenide optoelectronic and microwave devices. The kind of cross-subsidization between these firms is not practiced in American industry, where materials suppliers are not related to their component-making customers.

Technology Dependencies

Electronic materials are generally so specialized that the impact of foreign dependence is limited to the electronics industry sector.

A major exception to this generality, however, lies in the area of ceramics, where the weakness of American packaging piece-part suppliers is a reflection of a general problem with much of the structural ceramic materials industry.

6. Computer Design Aids and Engineering Simulation

Description

Computer design aid and engineering simulation technology includes work-stations and software, as well as the process characterization, necessary to mechanize much of the design and verification tasks in development of electronic system and subsystem, component, and devices designs, and their manufacturing processes.

Why is this Technology Important?

Computer design aids and engineering simulation are essential to the design and verification of today's electronic equipment and systems. Sheer complexity at all levels of the electronics technology, from devices to component to systems, including software, has exceeded human intellectual and physical capabilities. Computer generation of design elements, and their integration to perform higher level system functions, is the only method available to handle this complexity consistent with rapid cycle time and error-free design. In addition, computer simulation is a critical element in establishing effective test procedures to verify performance of finished electronic products.

In addition to individual tool capabilities, computer design aids and computer data communications capabilities facilitate coordination of teams of designers working on a single project, whether or not they are in the same location.

U.S. Position with Respect to the Res[illegible]he World

U.S. work-station and software producers continue to lead the world, both in machine performance and software capability. U.S. companies have been able to absorb a broad spectrum of computer-aided design and engineering simulation results from successful university electronics research and incorporate them into useful products which significantly improve the productivity of electronics design personnel. In the semiconductor field, for instance, although complexity of integrated circuit logic products has continued to double every eighteen months, chip design project staff size and turnaround times have remained the same or fallen slightly.

Most U.S. computer-aided design tools are generally available to electronics firms throughout the free-world, consistent with U.S. export restrictions.

Factors Enhancing U.S. Competitiveness

U.S. strength in the computer industry is reflected in leading microprocessor capability that forms the heart of engineering work-station hardware, and in the power and utility of design software tools. This capability has arisen from efforts of both large and small firms, and represents the aggressive efforts of the overall national computer design aids community.

Computer design aid technology continues to evolve rapidly as new graphics, verification, test generation, simulation and countless other routines arise from industry and university efforts. University accomplishments have been particularly important in this area, as they have been of high quality and quickly propagated throughout the technical community. U.S. graduate students trained in this area have formed the core of many start-up design aids firms.

Factors Detracting from U.S. Competitiveness

One weakness in U.S. computer design and engineering simulation capability has been the investment of time and care in process characterization. The raw data on which simulation results depends stems from a data base of process measurements which assure the physical relevance of simulation results. While U.S. understanding of physical principles underlying manufacturing processes is generally strong, characterization data taken from manufacturing processes is often incomplete, or not routinely collected during production. With their persistence and attention to detail, Japanese firms have not had this weakness.

Technology Dependencies

Computer design aid and engineering simulation technology used for electronic device, component, and system development provides powerful capabilities for use in a broad spectrum of other industry segments, from mechanical design to software to airfoil design to molecule synthesis.

Continued U.S. success in this critical capability depends upon sustained American leadership in microprocessor products, computer communications and software development.

7. Integrated Circuit Memory Technology

Description

Integrated circuit memory technology comprises both the design and fabrication process techniques needed to produce high density, high speed, reliable memory chips. Integrated circuit memories are semiconductor integrated circuits that perform electronic memory functions in electronic systems. Several types of memory, including dynamic random access memories (DRAMs), static random access memories (SRAMs) and electronically-programmable read-only memories (EPROMs) are so widely used that they have become commodity components.

Why is this a Critical Technology?

Memories are the most widely used, standard integrated circuits. As such, they are vehicles for learning high volume semiconductor manufacturing techniques. Because leading edge memory products are the most complex integrated circuits produced, lessons learned from production scale-up, yield improvement, process control, and cost reduction can be later applied to other types of complex integrated circuits, with similar results.

Memory size, speed, volatility and power dissipation determine many important performance characteristics computer-based electronic products.

In addition, the leading edge of memory device and processing technology continues to advance rapidly, one step ahead of that used in other integrated circuit applications. As a result, memories are often thought of as "technology drivers" -- products that serve as development vehicles for future technology.

U.S. Position with Respect to the Rest of the World

U.S. producers lost their early lead in memory technology as Japanese and Korean competitors concentrated on strengthening their memory competence, particularly in dynamic RAMs. Several Japanese companies reached parity with their U.S. rivals about 1980, and pulled well ahead thereafter, by emphasizing product quality and reliability, making major investments in production capacity, and pursuing long range development of future product generations. More recently, Korean firms have made significant investments in memory production capacity, and have captured a share of the world memory business. U.S. producers currently have a 20% share of the world DRAM production market.

U.S. firms chose to gradually withdraw from commodity memory businesses, starting with DRAMs. Only two U.S.-owned companies still produce DRAMs and, while the U.S. SRAM position is somewhat stronger, it is still seriously threatened. American companies retain some leadership in EPROMs, although this is the smallest commodity memory segment.

Factors Enhancing U.S. Competitiveness

U.S. companies have historically been the innovators in memory technology, although the weight of accumulated Japanese attention and investment in integrated circuit memory technology and production capacity is now paying them off with significant memory technology and manufacturing advances.

Buoyed by a still strong computer and electronic systems industry, the U.S. integrated circuit memory market remains the world's largest. This market is easily available to U.S. producers with technologically and price competitive, reliable products.

Factors Detracting from U.S. Competitiveness

The memory portion of the integrated circuit business is the most capital intensive part of the semiconductor industry. This is the leading edge for most process developments. Both production and R&D investments in this field require large, continuing investments to keep up with the rapid pace of continuous technological change. The decision of several large Japanese IC producers to concentrate a major portion of their efforts on memories over the past 15 years has resulted in an accumulated lead and market position that is exceptionally difficult to overcome.

Additionally, Japanese concentration on high quality, high volume production techniques has paid off in efficient manufacturing learning as Japanese companies have gained dominant position in the world memory business.

Technology Dependencies

Many lessons learned in manufacturing large numbers of memory circuits are directly transferable to other integrated circuit production processes. Lead in commodity IC memory technology gives a boost in manufacturing other integrated circuit technologies.

Memory circuits, especially SRAMs and EPROMs, are often included in complex VLSI circuits such as microprocessor and gate and cell arrays. Knowledge gained in producing memory integrated circuits can be directly applied in these other areas.

8. Integrated Circuit Logic Technology

Description

Integrated circuit logic technology comprises the collection of device and process technologies used to fabricate integrated digital logic chips. A variety of device and process technologies, both bipolar and MOS are included that produce a wide range of chip complexity, switching speed and power dissipation characteristics.

Why is this a Critical Technology?

Integrated circuit logic forms the heart of digital electronic OEM products. Simple IC logic chips are standard catalog items, available from many suppliers. For more complex chips in the VLSI class, standard logic chip offerings are fewer, often microprocessors, their peripheral components, and ASIC gate and cell arrays. Many VLSI chips are custom designed to suit specific customer applications.

Characteristics of the logic employed in an OEM product can determine many of the system's operating characteristics. Frequently, particularly at the VLSI level, proprietary system technology is embedded in custom logic chips.

Integrated circuit logic technology is the basic chip technology of many integrated circuit products, such as microprocessors and ASICs, where U.S. firms retain world leadership.

U.S. Position with Respect to the Rest of the World

The U.S. position in integrated circuit logic is not as weak as its corresponding memory position. While they are not clear leaders, U.S. producers are currently competitive in many logic technology areas such as CMOS. The Japanese have a strong position in high speed logic such as ECL, which is critical in high speed applications such as supercomputers.

Factors Enhancing U.S. Competitiveness

Leading OEM equipment manufacturers are reluctant to release sensitive custom chip design information to IC suppliers who are also strong OEM equipment competitors. Given the vertically integrated nature of virtually all major Japanese integrated circuit suppliers, the preference of many U.S. OEM suppliers is to deal with noncompeting (U.S.) suppliers, given the chance.

Most American integrated circuit producers have concentrated their technical development efforts on logic technology, as it forms the basis for leadership in product areas at the core of their business.

Factors Detracting from U.S. Competitiveness

U.S. producer weakness in the commodity memory business denies them the learning associated with high volume production of leading edge IC products. As a result, many U.S. competitors must strive to gain learning experience late in the process technology cycle, on smaller unit production volumes.

Japanese vertically integrated electronics firms are concentrating on those IC logic technologies that are critical to their own leading edge OEM equipment businesses.

Technology Dependencies

Integrated circuit logic technology strongly influences OEM equipment performance. Loss of competitive IC logic capability would quickly be reflected in loss of competitiveness for OEM electronic equipment producers, weakening the strongest remaining portion of the electronics industry.

9. Display Technology

Description

Display technology consists of a collection of various technologies used to present images on flat surfaces for user viewing. The most critical of these technologies are those used in black-and-white and color flat-panel displays including liquid crystal, electroluminescent, plasma, vacuum fluorescent, field emission and light emitting diode arrays. While the principles behind many of these displays are simple, the need for high resolution, large area, defect-free, inexpensive displays makes competitive display and display materials production an extremely sophisticated matter. In addition, the drive circuitry required for those types of displays that require high voltages can be costly.

Why is this a Critical Technology?

The rise of sophisticated products such as high definition television, portable computers, digital instrumentation for automobiles, and computer-driven weapons systems has greatly increased the need for high quality, compact displays capable of presenting large amounts of information, often in color. Since much of this equipment is portable, compatibility with battery operation, ruggedness, reliability, and operation over a broad range of environments are also critical issues.

The display interface dominates the user's interaction with many consumer and computer OEM products, hence availability of the right display to suit a specific application can make an important difference in user acceptance.

Display technology has increased in importance during the past decade. Emphasis on portable products, combined with the trend to larger size and higher resolution for television and computer products have rendered cathode-ray tube displays unusable in many instances, and past crude flat panel digital displays inadequate to meet foreseeable needs. Future consumer and professional products will make even more use of high resolution graphics and images, so that display technology must continue to improve still further.

U.S. Position with Respect to the Rest of the World

Japanese companies dominate many display technologies. Two Japanese companies have a commanding lead in liquid crystal displays, and several Japanese firms have invested heavily in development of other flat-panel display technologies. New flat-panel display technology development efforts in the United States are concentrated in small start-up firms, each exploiting a particular technology, or in military contractors who are developing special purpose displays for weapons systems applications. Neither has extensive display production experience.

The strong position once held by U.S. manufacturers in cathode-ray tubes largely disappeared with loss of strength in the consumer television business.

Factors Enhancing U.S. Competitiveness

U.S. OEM equipment firms need high resolution displays in many future products employing computer graphics and image processing and display. American firms lead in systems technology for many of these applications, and should provide a large, open market for leading edge displays.

U.S. firms have many of the technological elements needed to design flat-panel displays and their supporting electronic drive components. Military display technology programs are underway that seek to develop display technology that is useful in both military and civilian applications.

Factors Detracting from U.S. Competitiveness

U.S. manufacturers lack the production experience necessary to produce large-area, high resolution display economically. Each usable display must have no flaws across its surface area -- a fabrication challenge of the same order as that for manufacturing complex integrated circuits.

Most of the specialized equipment and materials needed for high volume, high yield flat panel display production are available only from Japanese sources.

Technology Dependencies

The low-defect manufacturing techniques needed for displays are similar to those common in integrated circuit production, only on an entire different scale. The same kind of attention to detail is essential to achieve economic manufacturing yields.

Industry Responses

The threat to the electronics industry is not new, and the industry has responded many ways.

Captive Production

The first response to endangered sources of supply was to integrate backward into the supply businesses. OEM computer firms started semiconductor processing operations, communications equipment companies established quartz crystal production, television set makers built picture tube factories, and telecommunications and government electronics concerns opened a variety of components and materials operations, from wire and cable to optoelectronics. Component manufacturers designed and built special production equipment for their processes.

These captive operations have met with mixed success. Those that concentrated on production of niche items that are not easily available of the open market, but which greatly affect product or process performance have remained -- those which attempted to duplicate open market products have, with only a few exceptions, failed.

Three large OEM-level corporations have managed to maintain on-going semiconductor manufacturing operations. IBM's internal production is estimated to be larger than that of any of the merchant market producers but one: NEC. AT&T's semiconductor production is more modest; it would rank sixth among U.S. merchant market producers. General Motors operations are much smaller. The few remaining captive producers are the exceptions. Companies such as Ford, Unisys, Wang, Honeywell, GE, Sylvania, Hughes, United Technologies, and Westinghouse all either closed their captive semiconductor efforts or have reduced them to specialized production or design operations.

The same happened among component suppliers. As long as processes were unique to individual companies, component firms stood to gain from customer production equipment. As soon as the standard processing steps required to fabricate integrated circuits became widely practiced, externally purchased equipment became cheaper and had better performance than could be realized in an internal production equipment operation.

The same applies to semiconductor materials. Only two merchant market semiconductor producers still maintain an internal silicon supply -- Motorola and TI. These are not intended to supply all the company's needs; they concentrate on materials types that are not generally available from external sources.

Thus, all but a few captive supply operations have shrunk to special purpose labs or niche suppliers. In spite of sizable investments in time, people and capital, they did not pan out.

Industry Associations

The electronics industry has established a number of industry associations to represent its common interests. EIA, AEA, CBEMA, SIA and SEMI are most active and have formed a focus for prosecuting many of the industry's interests in Congress and the administration. These organizations' activities emphasize tax reform, trade policy issues and consortium formation.

Consortia

The electronics industry has been a leader in establishing industry consortia to facilitate pooling of industry-wide resources to accomplish common ends.

The Semiconductor Research Corporation (SRC), was the first electronics pooled effort. SRC is a mechanism for pooling industry funds to promote university graduate research and education in the solid state field.

The Microelectronics and Computer Technology Corporation (MCC) was formed to carry out pre-competitive research in computer, communications and component technology. It drew together researchers from component and OEM firms in seven internal projects, ranging from supercomputer architecture to CAD and packaging.

SEMATECH, the semiconductor manufacturing consortium, is focussing on the component/materials and equipment level interface in its effort to develop more effective manufacturing technology for the semiconductor industry. After two years of operation, SEMATECH has scaled back an originally aggressive internal development program to concentrate on helping materials and equipment concerns meet semiconductor production needs.

These consortia are addressing many of the challenges noted in the challenges section. However, shared development activities are still new to many electronics firms who are used to a "go-it-alone" style of business, and many management challenges remains to be overcome to make the best advantage of consortia opportunities. Two problems, technology transfer back to sponsoring firms, and effective, constructive participation in consortia by member management, remain to be overcome. The effectiveness of the consortium approach to R&D remains to be convincingly demonstrated.

Japan Thrust

Stung by criticism that they "had not really tried to sell in Japan", leading electronics firms have established a variety of selling, marketing, manufacturing and development operations in Japan. Notable examples include IBM's massive Japanese manufacturing and marketing effort, HP's joint venture, TI's and Motorola's semiconductor manufacturing plants, and numerous other joint ventures.

Accompanying these in-country activities, electronics companies have prosecuted numerous trade actions before agencies of the U.S. government. The earliest of these, including an action by Zenith over unfair competition in the consumer electronics field, were won, but were too late to be of substantial benefit to damaged parties. More recent actions regarding dumping of pagers and cellular telephones have been more timely. Aggressive use of U.S. government trade negotiators to help open Japanese regulated markets has been partially successful in opening NTT's purchasing practices and cellular telephone networks.

Continuing Investment in R&D and Capacity

Electronics companies continue to make sizeable investments in R&D and fixed plants and equipment. While the time horizon for many R&D efforts has been shortened, the increased costs of creating more expensive technology and the rapidly escalating costs of sophisticated production and test equipment has meant that the fraction of sales invested by companies in R&D and capital expansion and improvement has remained high. In spite of this, U.S. electronics firms are being outspent by Japanese competitors.

Industry Impediments:

Based on the foregoing, it is clear that the U.S. electronics industry faces a number of impediments to retaining leadership in those areas where it now leads, and regaining a viable position where it is now behind. The following are the most serious problems:

The need to strengthen vertical relationships within the industry which allows risk and reward sharing between levels of the industry structure and provides some protection against the highly cyclical nature of the electronics industry. The vulnerability of independent parts of the industry structure poses a problem for the entire framework. In the United States, this means strengthening the vendor-customer bonds which hold the vertical structure together.

Cost of Capital is an intense problem for an industry as capital intensive as this one, when it is faced by competent, less expensively financed competition.

The rise of consumer products and their associated components and manufacturing technology caught the U.S. electronics industry by surprise. The effects of not having a healthy consumer electronics segments are far reaching, both vertically and horizontally.

Market access is critical to achieving return on industrial investment. As noted above, the barriers to entry into the Japanese market, whether they result from governmental restrictions or company practice, give Japanese manufacturers substantially greater market opportunities than their non-Japanese competition. Future problems with access to the post-1992 European market could pose a still further problem in worldwide electronics competition.

R&D effectiveness is threatened because the structure of U.S. technology development is evolving from a primarily internal industry activity to a distributed one involving academia, government laboratories, consortia and joint ventures as well as individual electronics firms. Experience to date with these new mechanisms indicates that much remains to be learned about effective management of shared development opportunities, and success of such a distributed system has not been demonstrated.

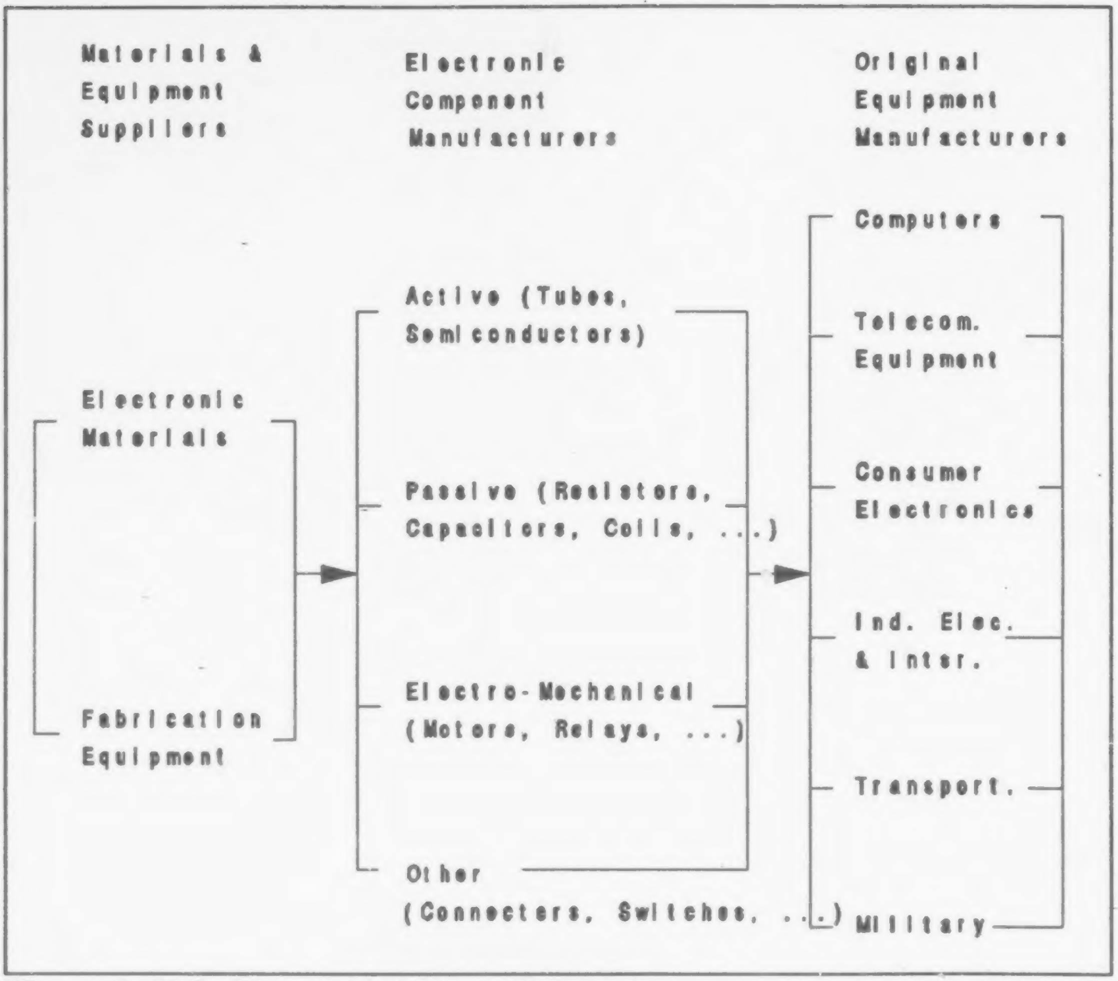
Technical skill availability is a long term problem for the U.S. electronics industry. As the sophistication of electronics technology continues to increase, the ability and number of people entering the U.S. work force to cope with future developments in the industry are falling short.

Leadership in setting operating standards for new electronic equipment is important to encourage U.S. OEM firms reach out to develop new products for untapped applications.

Industry-wide Priority Goals:

1. Implement effective mechanisms for overall coordination of multi-level activities to share risk and reward throughout the industry structure.

2. Regain a volume production driven industry - e.g., next generation consumer electronics
3. Address Cost of Capital
4. Penetrate all important markets abroad
5. Maintain a sufficient technical skill base in United States.
6. Emphasize continued investment in R&D, capacity expansion and standards.


Materials &
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Manufacturers
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Equipment
Manufacturers
Computers
Active (Tubes,
Semiconductors)
Telecom.
Equipment
Electronic
Materials
Passive (Resistors,
Capacitors, Coils, ...)
Consumer
Electronics
Ind. Elec.
& Inter.
Electro-Mechanical
(Motors, Relays, ...)
Fabrication
Equipment
Transport.
Other
(Connecters, Switches, ...)
Military

Figure 1: U.S. Electronics Industry Structure

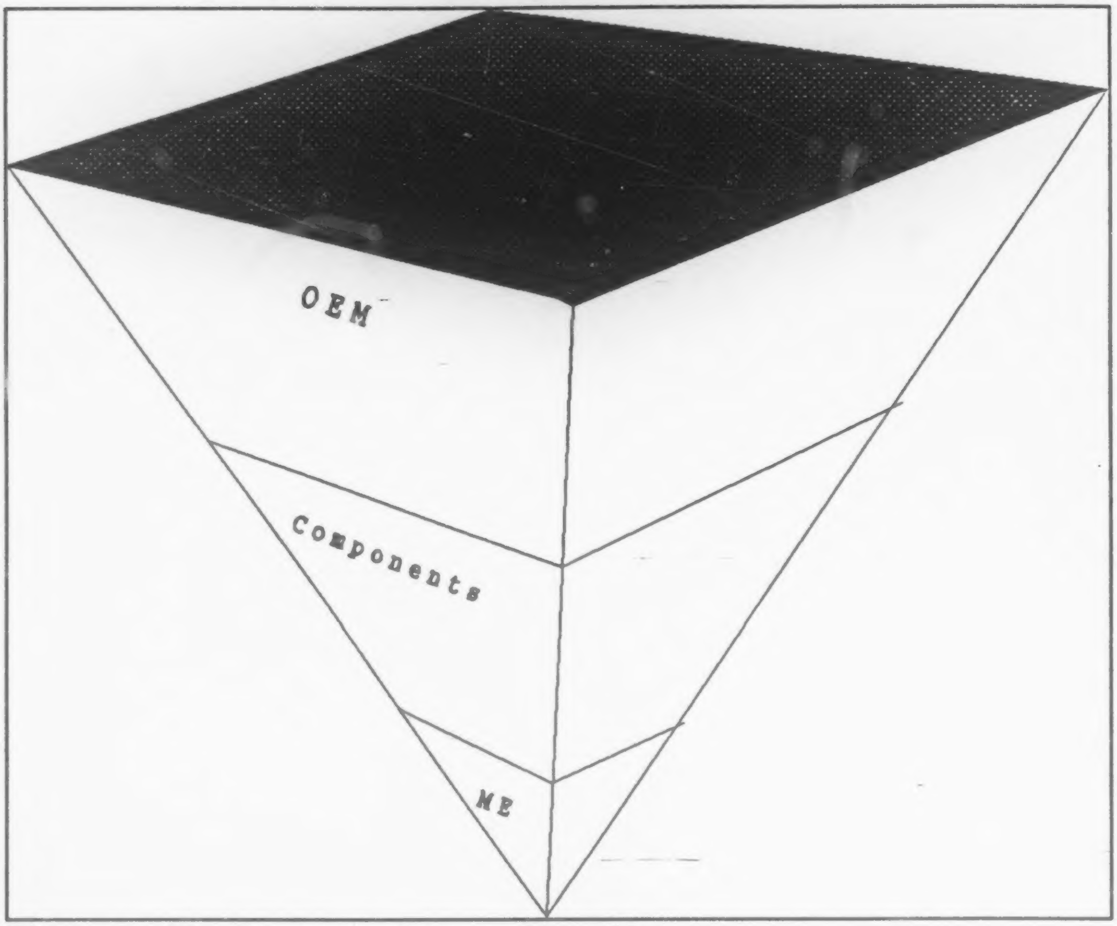
OEM
Components
ME

Figure 2: The Electronics Industry Pyramid

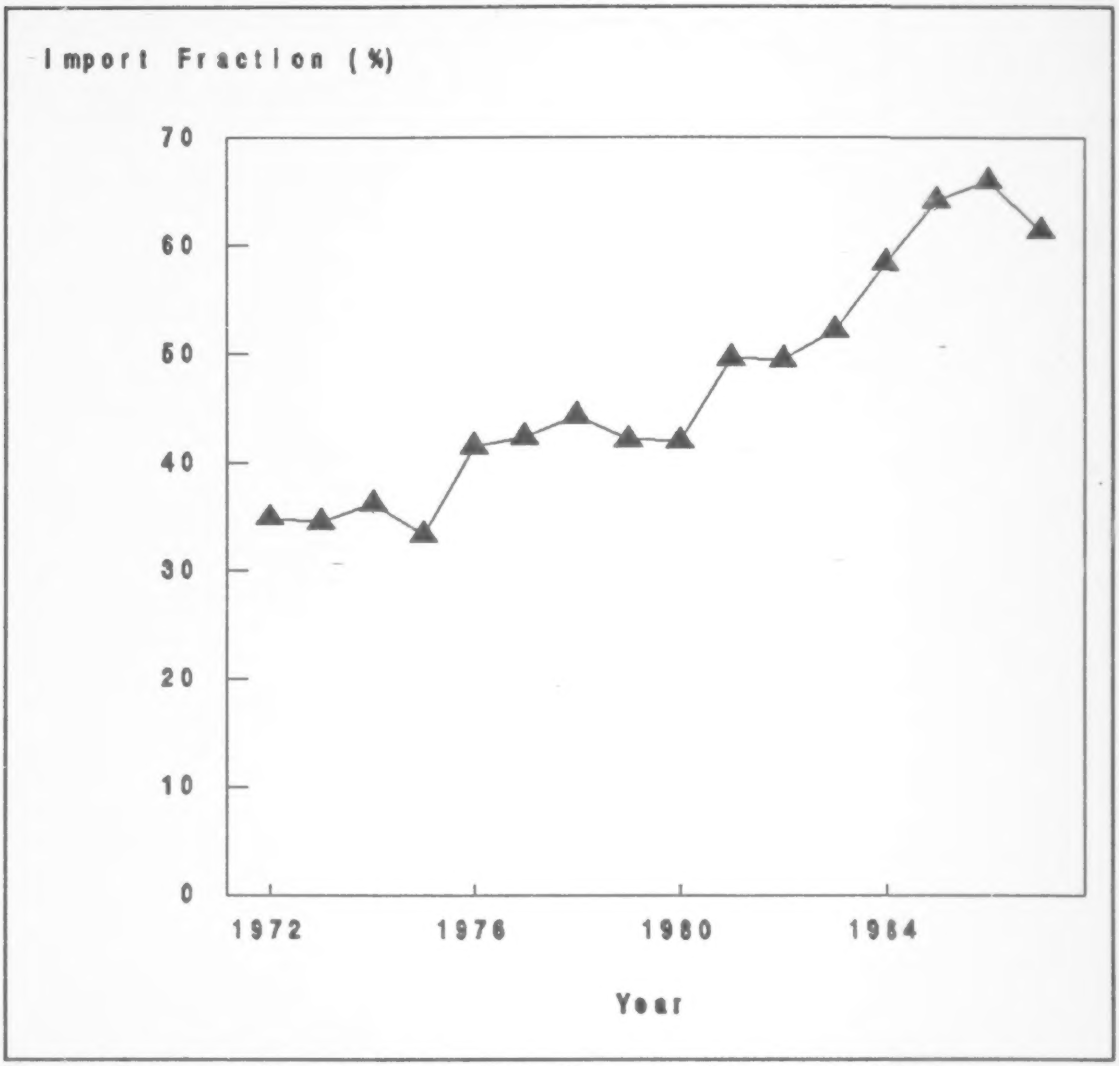

Figure 3: Import Fraction of the U.S. Consumer Electronics Market
Source: 1989 U.S. Industrial Outlook (more recent data not available)

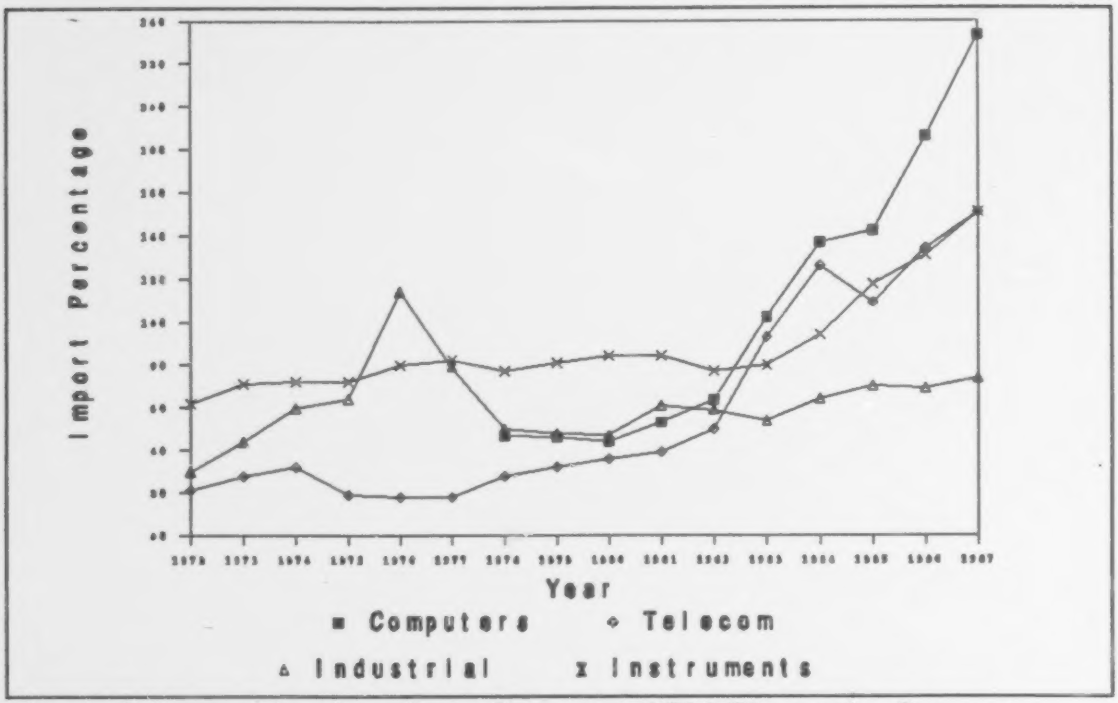

Figure 4: Import Fraction of non-Consumer OEM Electronics Segments. Source: 1989 U.S. Industrial Outlook (more recent data not available)

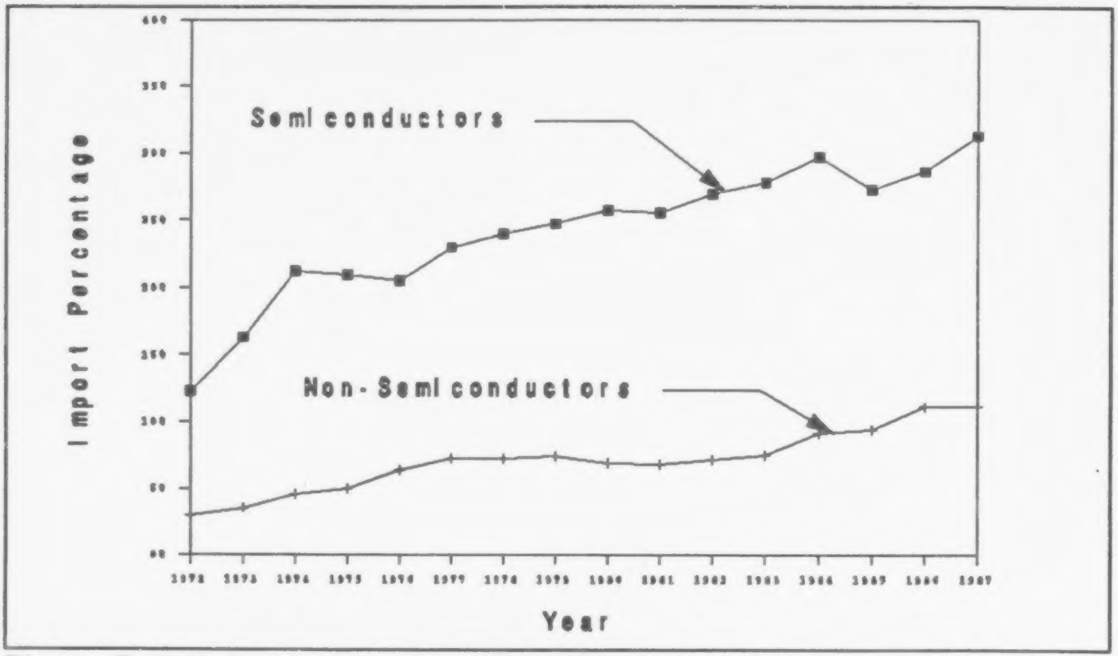

Figure 5: U.S. Import Fraction -- Components.
Source: 1989 U.S. Industrial Outlook (more recent data not available)

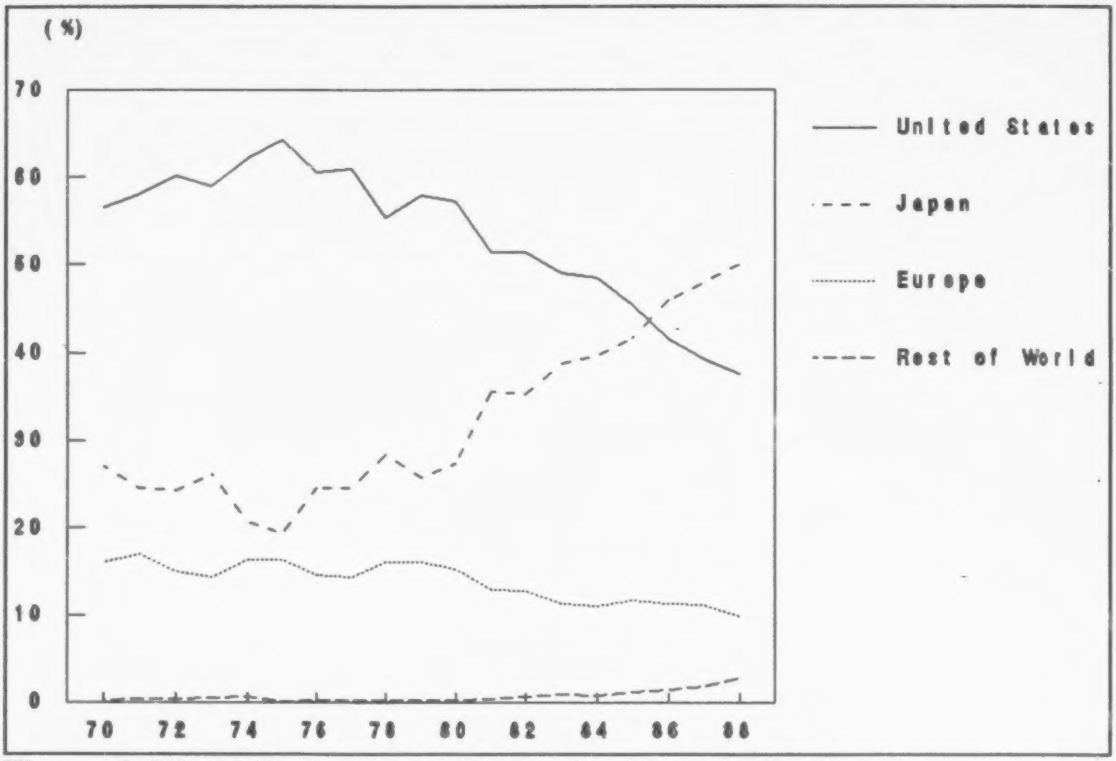

Figure 6: World Semiconductor Production Share by Region.
Source: Dataquest

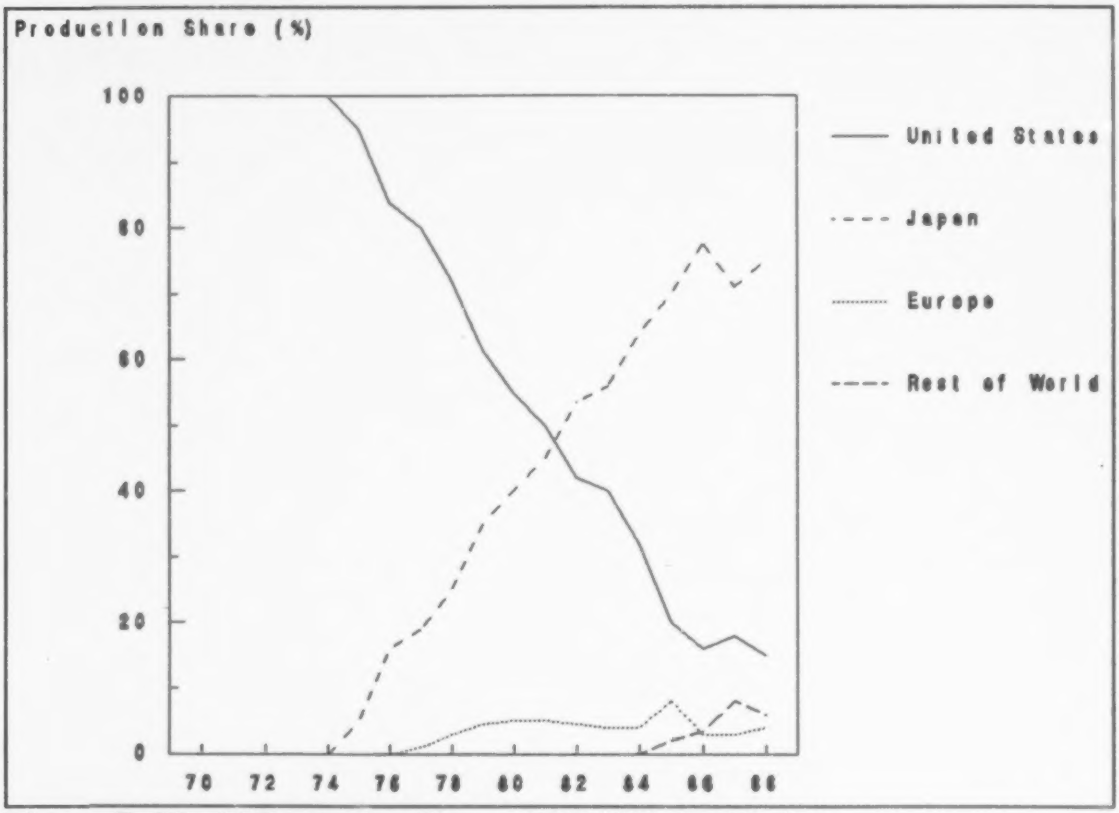

Figure 7: World Production Share of DRAM's by Region.
Source: A Strategic Industry at Risk

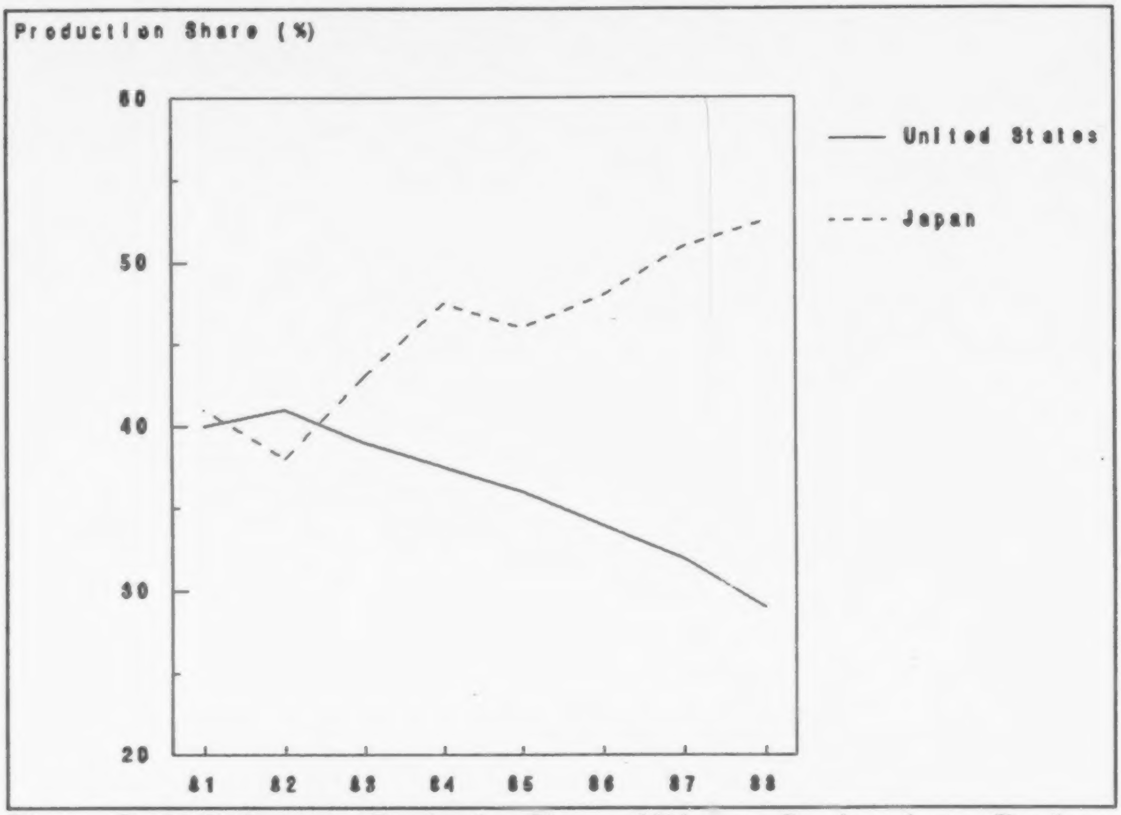

Figure 8: U.S./Japanese Production Share of Discrete Semiconductor Products
Source: A Strategic Industry at Risk

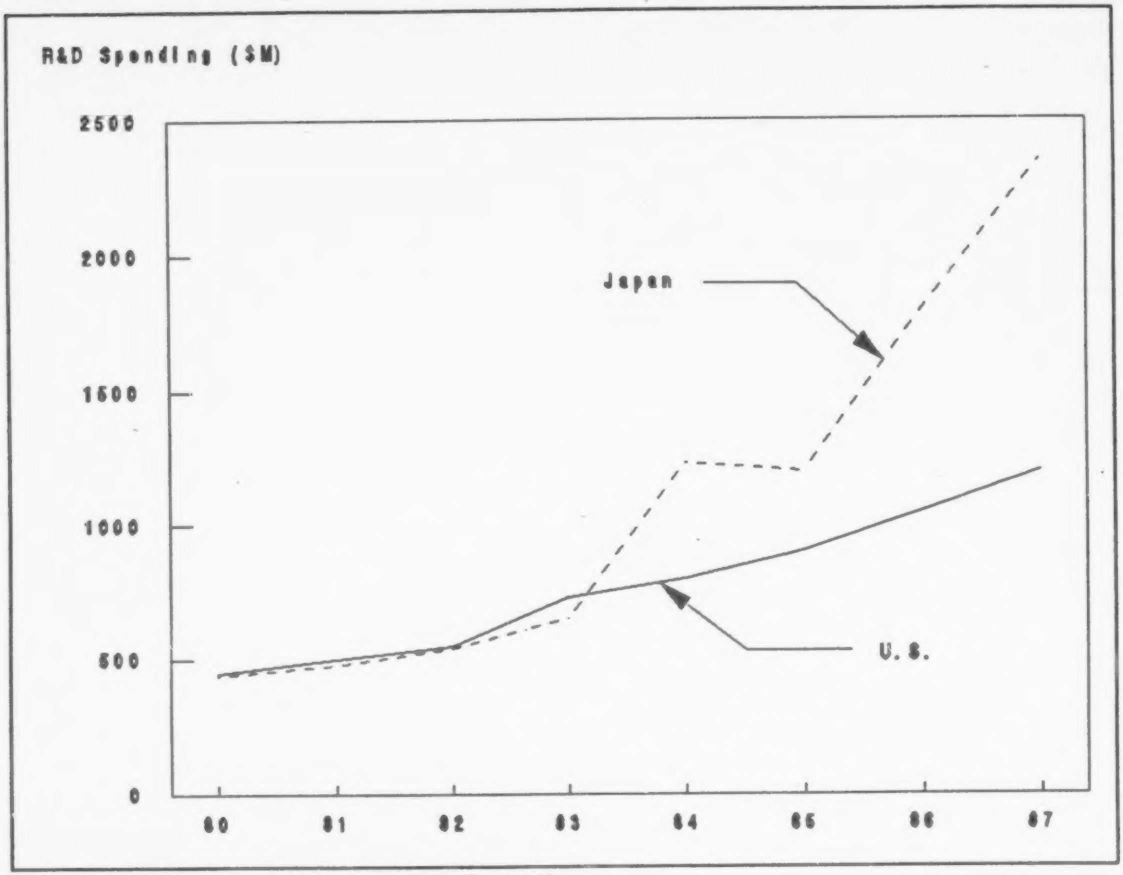

Figure 9: Semiconductor R&D Spending.
Source: OECD

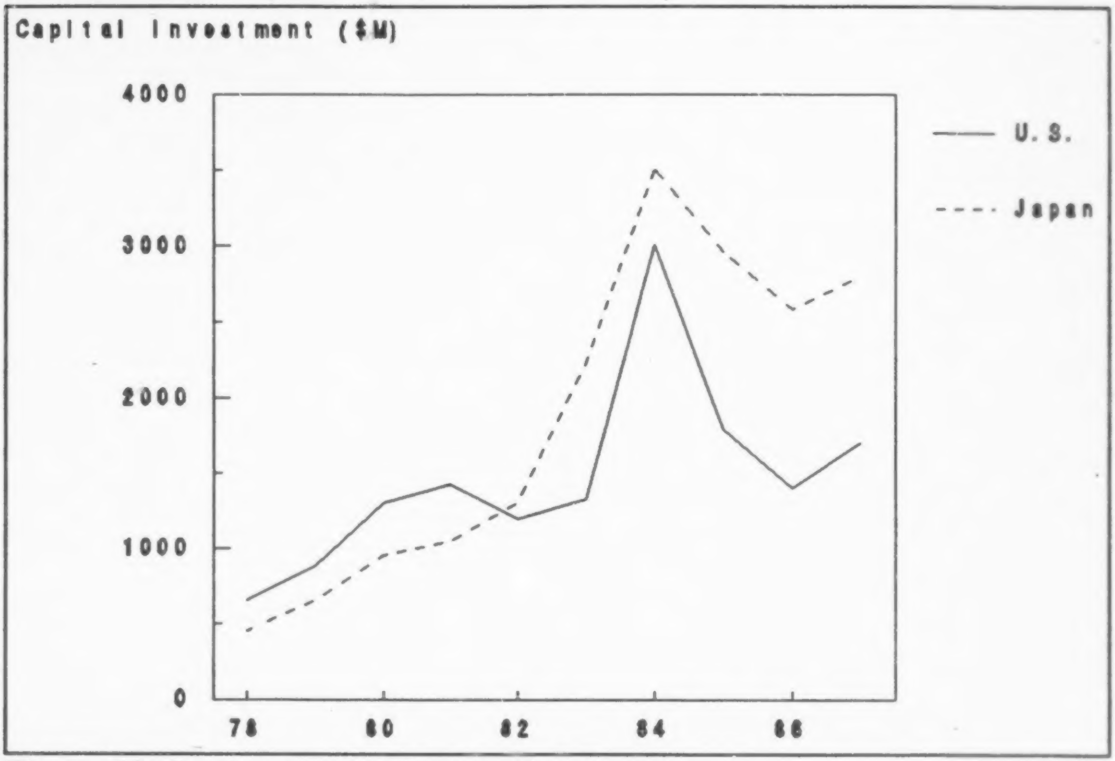

Figure 10: Semiconductor Fixed Capital Investment
Source: OECD

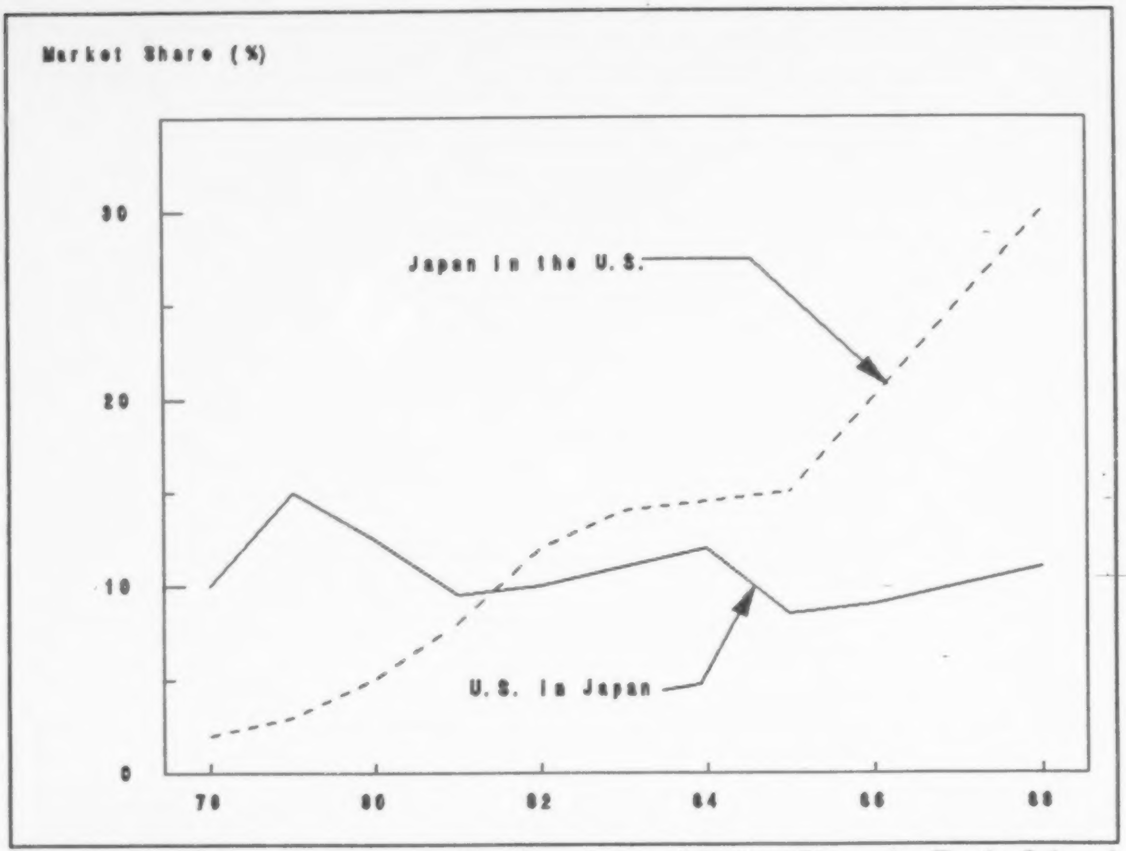

Figure 11: U.S. and Japanese Semiconductor Market Share in Each Others' Home Market.
Source: A Strategic Industry at Risk

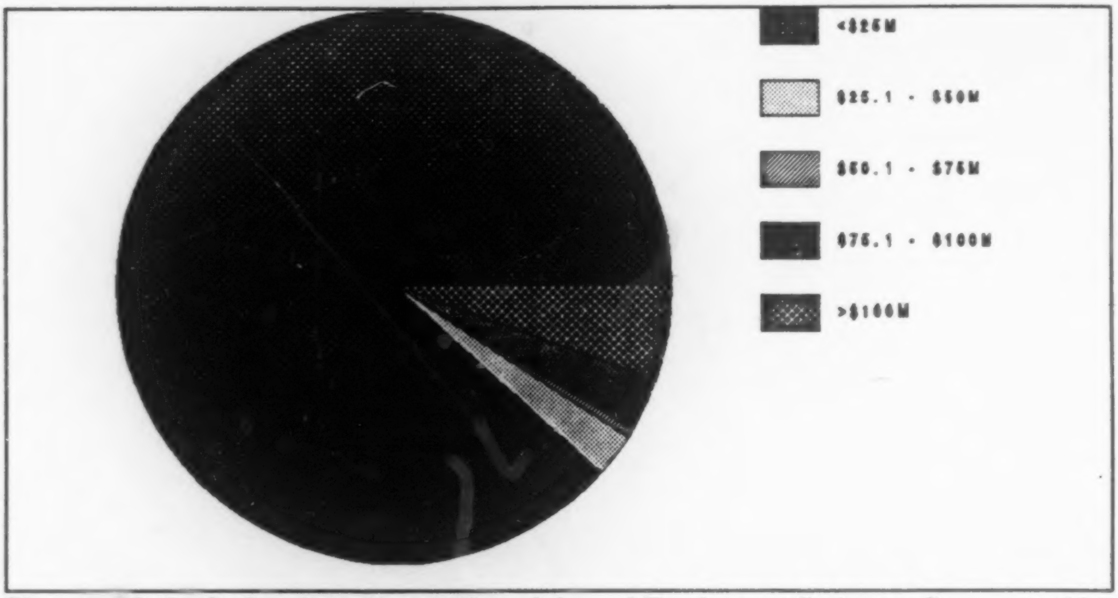

Figure 12: U.S. Semiconductor Materials and Equipment Industry Segmented by Producer Annual Sales
Source: A Strategic Industry at Risk

Table I: Largest Electronics Firms (1988)
Source: IEEE Spectrum, January, 1990, p.55)

Company and Country	Electronics Sales	Electronics % of Co. Sales
IBM (United States)	$59,681M	100%
Matsushita Elec. (Japan)	$30,102M	70%
NEC Corp. (Japan)	$24,086M	100%
Philips NV (Netherlands)	$22,941M	72%
Hitachi Ltd. (Japan)	$22,504M	45%
Toshiba Corp. (Japan)	$20,786M	70%
Siemens AG (West Germany)	$19,229M	57%
Fujitsu Ltd. (Japan)	$18,562M	100%
General Motors (United States)	$16,088M	13%
AT&T Co. (United States)	$14,436M	41%

Table II: 1989 OEM Electronics Production by Region (Millions of $).
Source: Dataquest

Company and Country	Semiconductor Sales
NEC Corp. (Japan)	$4,964M
Toshiba Corp. (Japan)	$4,889M
Hitachi Ltd. (Japan)	$3,930M
Motorola, Inc. (United States)	$3,322M
Fujitsu Ltd. (Japan)	$2,941M
Texas Instruments (United States)	$2,787M
Mitsubishi Electric (Japan)	$2,629M
Intel Corp. (United States)	$2,440M
Matsushita Electric (Japan)	$1,871M
Philips NV (Netherlands)	$1,690M

Table III: World's Largest Merchant Market Semiconductor Makers is 1989.
Source: Dataquest

	No. Am.	Eur.	Japan	ROW	World
Computer	108,941	48,164	57,609	18,650	233,364
Telecom	29,915	22,066	24,746	7,035	83,762
Consumer	20,457	20,324	56,500	25,677	122,958
Ind./Inst.	46,899	28,582	26,956	617	103,054
Transport.	11,292	6,611	15,275	1,398	34,576
Military	51,727	23,264	0	405	75,396
Total	269,231	149,011	181,086	53,782	653,110

Table IV: Top Semiconductor Fabrication Equipment Suppliers' Worldwide Sales, 1982 and 1988.
Source: A Strategic Industry at Risk

1982		1988	
Perkin-Elmer (U.S.)	$162	Nikon (Japan)	$521
Varian (U.S.)	$100	TEL (Japan)	$508
Schlumberger (ROW)	$96	Advantest (Japan)	$385
Advantest (Japan)	$84	App. Mat. (U.S.)	$382
App. Mat. (U.S.)	$84	Gen. Signal (U.S.)	$375
Eaton (U.S.)	$80	Canon (Japan)	$290
Teradyne (U.S.)	$79	Varian (U.S.)	$211
Canon (Japan)	$78	Perkin-Elmer (U.S.)	$205
Gen. Signal (U.S.)	$77	Teradyne (U.S.)	$190
Nikon (Japan)	$58	LTX (U.S.)	$180

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

The Council on Competitiveness would like to thank William G. Howard for preparing this profile.

The Council would like to thank Pfizer Inc. and NMTBA/The Association for Manufacturing Technology for their assistance in publishing the profiles.

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*Dr. Spencer served on the Committee in his role as Vice President, Science and Technology, Xerox Corporation, prior to his appointment to Sematech.

ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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A COMPETITIVE PROFILE OF THE

MACHINE TOOL INDUSTRY

Research Paper for

GAINING NEW GROUND:

TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future*.

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling and $20 for *Gaining New Ground* plus $2.50 postage and handling.

Sectoral Profile: Machine Tools

Key Points

- Machine tools are the **critical link** between intermediate products formed from raw materials and finished discrete components. Machine tools therefore have leverage across most industries since the production of virtually all goods and services is dependent on a machine tool or a machine that was built by a machine tool.

- The industry is **small** in terms of number of firms (about 600), employment (median is about 60 people per firm) and average sales (about $7 million per company). This industry structure makes it difficult for machine tool builders to keep up with the technical needs of their customers, who are often large, integrated manufacturers.

- The industry is characterized by steep business cycles and uncertain income streams. During the 1980s, sales fluctuated between $2 and $5 billion annually. These market fluctuations discourage investment in R&D and the rapid diffusion of new technology. During the past two decades, investment in R&D has averaged less than 2 percent of sales.

- The U.S. share of world production has declined steadily since 1955, from about half to about 10 percent. By contrast, Japan has grown from a 1 percent share of world production to 23 percent to become the world leader, and Germany has maintained its share its approximately 16 percent share. Supported by an active government policy, Japan has focused on low cost, high quality, volume production of standardized products. They also have universal control capability that dominates the market. Germany and Switzerland have adopted a strategy focused on high performance, specialized niche products.

- Since 1978, the U.S. has had a trade deficit in machine tools. Import penetration of the domestic market has increased dramatically, now accounting for a 50 percent share.

- The U.S. industry continues to face problems related to the adoption of new technology and the use of flexible manufacturing systems. Japan has an installed FMS capability that is not matched by U.S. companies.

- The loss of firms and market share in the U.S. machine tool industry has seriously affected U.S. mobilization-surge capacity in a time of national emergency.

Factors Supporting Development of Critical Technologies

- The United States is still near the top in terms of world machine tool consumption. The large domestic market could be the basis for the U.S. machine tool industry regaining leadership in critical technologies.

- Strong relationships with its customer base, in such areas as simultaneous engineering, could result in a symbiosis which would raise the competitiveness of both the machine tool industry and its customers.

Impediments to the Development of Critical Technologies

- Technological leadership requires a financially healthy industry with the resources to invest in new products and processes. Financial health will only come with an internationally competitive industry that is free to pursue opportunities worldwide in the now global machine tool market. Factors inhibiting the ability of the U.S. machine tool industry to accumulate the resources to pursue R&D in critical technologies include:

  · small firm size in the industry;
  · industry cyclicality;
  · U.S. export control policy;
  · U.S. tax laws;
  · the U.S. product liability system.

Critical Technologies

- Advanced materials technologies, metallurgy, physics of materials and dynamics of structures.

- Electronic controls, metrology and sensors technology.

- Software and artificial intelligence.

- Laser technology and advanced precision bearings.

STRATEGIC SECTORAL PROFILE

THE U.S. MACHINE TOOL INDUSTRY

I. STRUCTURE AND IMPORTANCE OF THE U.S. INDUSTRY

Machine tools transform castings, barstock, or sheet metal into finished components. Machine tools are thus the critical link between intermediate products formed from raw materials and finished discrete components. These components are then assembled either into end products or into yet other machines that will in turn make end products.[1]

All manufactured goods, directly or indirectly, require the use of machine tools, so they are considered vital to the nation's competitiveness. The major users of machine tools are the fabricated metal products, machinery, and transportation industries. The U.S. machine tool industry ranks fourth in world machine tool production, behind Japan, West Germany and the Soviet Union.

Manufacturing technologies, worldwide, are rapidly changing. Advances in computers and electronics technology substantially changed the traditional industry beginning around the mid-1970s.

The introduction and evolution of computer numerical controls have led to significant increases in the productivity of machine tools. By adding ancillary equipment (material handling devices, robots, automatic guided vehicles, etc.) to connect two or more machines in a system under computer numerical control, it is possible to form flexible cells and systems capable of machining families of workpieces in small quantities, even in single quantities, or in continuous production.

Parallel developments in the field of computer-aided design and manufacturing systems have made it possible to establish computer links between the design and the manufacture of the product (e.g. the dimensions of a part to be machined are carried over from the design phase to the machining of the part). This greatly improves the flexibility of these systems and results in shortened lead times. It also eliminates the need to inventory parts because they can be machined quickly using the appropriate part programs stored in a computer.

Different concepts have evolved in the design and application of flexible manufacturing systems. The U.S. machine tool industry pioneered the technology required to produce multi-function machining centers and flexible machining and manufacturing cells and systems. While the United States is regarded as a leader among the world's machine tool builders in technology and experience, the U.S. industry has been overtaken in many areas, as Japanese and European machine tool builders innovate in design and application.

Industry Structure

- In 1987 (the last year reported) there were 624 machine tool builders, with only 352 having more than 20 employees.[2]
- The median number of employees for firms in the industry during 1989 was about 60.
- The typical U.S. machine tool company had sales of just $7 million per year in 1989.
- The production of U.S. machine tools during the 1980s fluctuated between $2.0 and $5.0 billion, reflecting the highly cyclical nature of the industry.

The U.S. industry is currently characterized by mid-sized family firms that have technical origins and tend to specialize in narrow product lines for particular markets. The structure of the industry was traditionally reinforced by reputations built around particular types of machines, and high tooling costs the user would incur by switching from one make to another. In the absence of modular design and flexible automation, production economies were not enhanced by broader lines, but by standard models and long product life-cycles. This design/production paradigm was not a problem as long as product-life cycles were long and there was no alternative production paradigm. It became increasingly dysfunctional, however, as new technologies (e.g. CNC) emerged and Japanese production capabilities changed the nature of competition by introducing new economies of scope and scale.[3]

The machine tool industry is dependent on the availability of key items from suppliers of motors, bearings, electronic controls and measurement devices. Over the last several years, important segments of the supplier base for these items have come under foreign control. Most of these critical items are now engineered and produced offshore and must be imported.

A close user-builder relationship is not only important to machine tool builders, but also to the manufacturing companies that use machine tools. Many U.S. users have shifted to foreign suppliers of machine tools because U.S. suppliers could not provide the leading edge equipment that was required or could not meet foreign price and delivery schedules. This situation, however, can put U.S. users at a disadvantage, since their foreign competitors often have access to the same leading edge equipment a year or two ahead of U.S. companies. In some cases the equipment is not even available to U.S. companies.[4]

The critical issue is that domestic machine tool user industries that are dependent upon foreign equipment for manufacturing key components will chronically lag their foreign competitors and will perpetually be trying to catch up rather than leading. If a manufacturing company's machine tools lag those of its competitors, so will the downstream equipment and products that depend on them.[5]

Industry Performance and National Defense

The loss of firms and market share in the U.S. machine tool industry has seriously affected U.S. mobilization-surge capability. Machine tools are fundamental in the production of the critical war-fighting components (e.g. tanks, missiles, ships, planes, transportation equipment, etc.). It has recently been estimated that 25 percent of the total consumption of machine tools in the United States is linked directly or indirectly to defense requirements. Past experience suggests that demands on the industry could rise 6 to 8 times higher during wartime. The high-level of import penetration in the U.S. market means that the mobilization base is heavily dependent upon foreign-based suppliers, who may prove unreliable in an emergency.[6]

In announcing the decision to seek Voluntary Restraint Agreements on machine tool imports in 1986, President Reagan acknowledged that machine tools were a small yet vital component of the U.S. defense base and that the high levels of imports could potentially erode U.S. capabilities to manufacture critical machine tool product lines. The U.S. Department of Defense has further recognized the industry's crucial role through its funding of R&D projects by machine tool companies. The "Buy America" provisions that have been inserted in Department of Defense appropriation bills have been inserted in an effort to reduce the U.S. dependency on imported machine tools.

A strong, viable domestic machine tool industry is needed to engineer, design, and build special machine tools for highly classified military applications, for example:

- The special multi-axis machines built to produce propellers for nuclear submarines requires technology not available commercially.

- In the aerospace industry, the computer-controlled tape laying machines required to measure, cut and lay down the composite layups used to build aircraft wings and fuselages requires expertise that only a few of the world's top machine tool builders possess. At present, U.S. machine tool builders are recognized for their leadership in this area.

Without an experienced engineering staff to design, build, and assemble special machine tools, the lead time to produce them in a time of national mobilization would be unacceptable.

The U.S. Machine Tool Industry's Technological Leverage Across other Industries

The leverage of the machine tool industry is broad-based because the production of virtually all goods and services are dependent on a machine tool or a machine that was built by a machine tool.

As key suppliers to manufacturing industries, machine tool builders are increasingly being called on to offer not just machines, but solutions to manufacturing problems. Many of manufacturing's competitive battles lie not in developing products, but in developing efficient, flexible and inexpensive manufacturing production processes.

While purchasers of machine tools are cutting costs and streamlining operations, machine tool builders must not only offer competitive products, but also ensure that those products make the customer more competitive. Machines must be integrated with customer programs such as "just-in-time" and total quality control. Today, the challenge to machine tool builders is not just to offer buyers machines. In addition, they must offer the following:

- Product designed to maximize flexibility and minimize the disruption and high cost of changeover.
- Product designed to minimize in-process inventory in order to reduce the working capital needs of the manufacturer.
- Product designed to enhance control and predictability of the manufacturing process through advanced sensor and feedback capability.
- Product designed to produce increasingly stringent part quality levels, thus reducing manufacturing costs.
- Product designed to blend the various industrial disciplines into a comprehensive package. This requires integration from product design/engineering through to product completion.

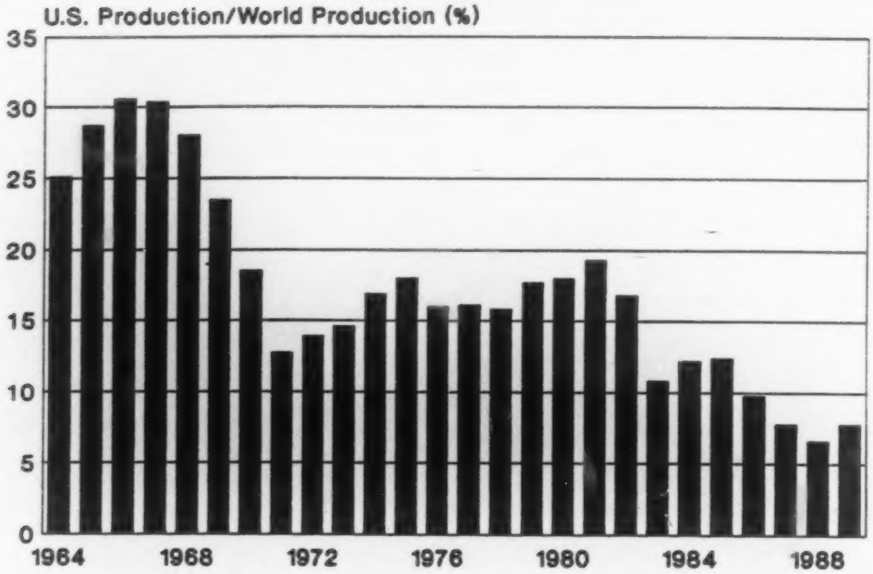
International Competition

The most notable trend in the industry during the past three decades has been the rise of Japan and the decline of the U.S. as a dominant international machine tool supplier. From less than 1% of world production in 1955, Japan grew to become the world leader in machine tool output in 1982. During the same period, the U.S. declined from just under half, to just over 10% of world production; Germany and Switzerland maintained their share; the U.K. and France suffered major declines; and Italy increased its share.[7] In addition, since 1978 the U.S. has had a trade deficit in machine tools. Import penetration of the domestic market has increased dramatically, now accounting for a 50% share.

Although there are European firms which produce high volume, standard machine tool products, many European companies are characterized as specializing in high-performance, precision-engineered, customized products. They need a large share of the world market in order to have enough volume to profit by producing specialized niche products. They are therefore driven by export strategies.[8]

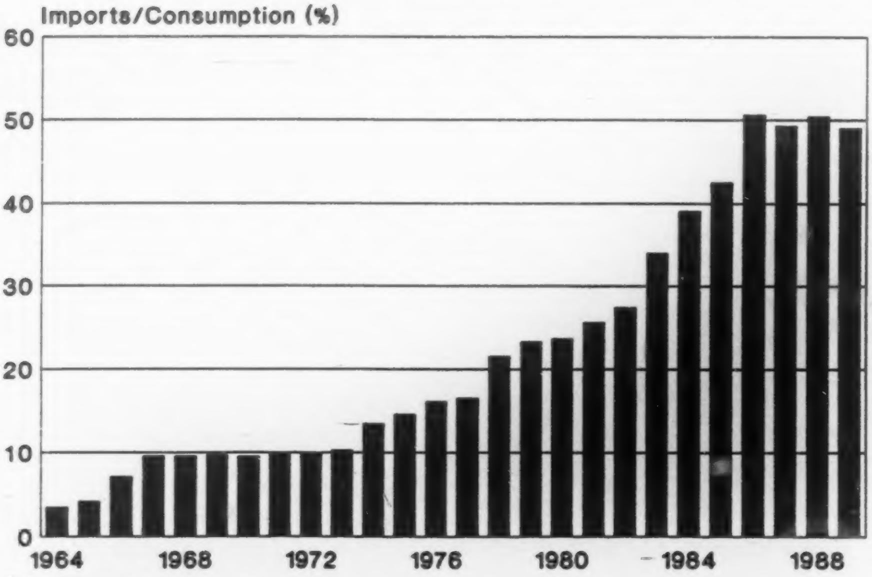
By contrast, the Japanese do not aim for specialized market niches, but for consistent, reliable, low-cost, standardized products that many different companies can use. They have concentrated on a few types of general purpose products for high volume markets. Exports are also an important part of their strategy because in order to generate economies of scale and offer low cost products, they need large production runs. In the past few years, the Japanese have ceded cost leadership at the low end of the market to the Koreans, Taiwanese and Brazilians.[9]

U.S. Share of World Machine Tool Production



Source: American Machinist

Import Penetration of the U.S. Machine Tool Market 1964-1989



Source: NMTBA

II. The Role of Technology

Innovation Processes

Budgeted R&D does not reflect the full technical effort of the industry, but it has traditionally been low. Estimates for the 1970s placed R&D at about 1.6 percent of sales. This declined to 1.3 percent in the 1980s. R&D has been concentrated in larger machine tool firms. There is however, a great deal of engineering and technical effort among builders, particularly those involved in special purpose and customized work.[10]

The small size of machine tool firms is in part responsible for the investment pattern in the industry, but U.S. conglomerates have also played a role. Profitable U.S. machine tool companies were attractive acquisitions for conglomerates in the 1960s and early 1970s, but the conglomerates did little to change the historically low level of R&D of the industry. Profit opportunities were viewed as inadequate to support major new technologies and innovation in the industry. The conglomerates failed to provide the greater investments necessary to develop new NC/CNC product lines.[11] The investments in controls and product upgrade which were made, were not enough to offset the market inroads a single Japanese controls manufacturer had achieved through its low cost, reliable controls. (A significant portion of this low cost advantage can be attributed to the overvalued dollar in the first half of the 1980s.) This single company maintained and enhanced its share of the world market through the aggressive pursuit of additional features.

One of the driving forces in developing new technology is user demand for advanced new products and processes. This kind of "technology pull" is critical in machine tools. Because machine tools are durable and have long product life cycles, machine tool builders rely on user growth and product change as the basis for developing more advanced kinds of tools. Unfortunately, until recently, many U.S. users did not focus on manufacturing process innovation essential to their competitiveness and did not work with machine tool builders to innovate and provide leading-edge equipment.[12]

Sometimes new machine tool technology derives from observation of inventions and developments in other fields, some related and some not related:

- The original concept of numerical control came from a small Michigan company. The concept was developed by Air Force-funded studies at MIT. The U.S. Air Force needed faster, less costly and more productive machinery systems to produce aircraft. NC was originally conceived as ideal for small lots, large aircraft parts, and adaptable to complex configurations. The U.S. Air Force purchased machines, and then installed them in the factories of prime and subcontractors, thus creating a growth in applications. The machine tool industry responded with the development of less sophisticated point-to-point machines which were more suited to the bulk of U.S. applications at the time. However, they were still confronted by user complacency and doubts about implementing this new technology.

- The development of semiconductors in the communications field led to a series of improvements in the capability of numerical control units.

- The servo control concepts developed during World War II for the U. S. Navy also made numerical control of machine tools practical.

- The machine tool industry introduced the numerically-controlled automatic tool changer, which made possible the machining center and flexible machining cells and systems that are the leading technology in manufacturing today.

- Hydrostatic bearings, which were developed for the steam and hydro turbine industries to carry tremendous loads with little or no friction, have made possible super-precision machine tools and enabled large, massive machines to be able to accelerate and decelerate at very rapid rates.

Critical Technologies

Machine tool design has evolved from basically mechanical mechanisms to highly sophisticated systems involving many different technologies. The following list represents the critical technologies that affect the capability and competitiveness of machine tools in manufacturing.

- Metrology
- Physics of materials
- Advanced precision bearings
- Electronic controls
- Artificial intelligence
- Laser technology
- Metallurgy
- Dynamics of structures
- Advanced materials technology
- Software
- Sensors technology

Each of these technologies is critical to competitiveness because each affects the performance and capability of machine tools. They are universal in their application, although each one may not be used in every machine type. The performance and characteristics of a particular machine are determined by the:

- basic mechanical and physical design of the machine;
- materials used in its construction;
- selection and application of various bearings;
- controls that direct the motion and speed of movement as well as the repeatability of the machine;
- software that commands the controls;
- sensors and measuring devices that inform the software in the controls about the operation and positions of the various elements of the machine tool.

Developing these critical technologies requires significant multi-disciplinary research and development programs. Even within these general research needs lies a large range of prerequisite and application-specific research programs. For example:

- Precision improvement includes tool sensing to correct for deviation from programmed tolerances; hardware/software monitoring, mapping and correction procedures; and positional and thermal sensing to compensate for structural errors.

- Sensing-research projects include the development of position transducers, so that sensors are accurate in increasingly higher-speed machining; sensor arrays to integrate the measurement taken during the various steps of the machining process; and the development of lower cost laser feedback systems.

- Computer software projects include expert systems and artificial intelligence; improved machine controls; and the development of a real-time, object-oriented computer language to develop numerically controlled machine software, as hardware development is constrained by the high cost of concurrent software development.

The complexity of these research undertakings is multiplied as advances in new materials and microelectronics continue. The scope and expense of such research efforts precludes all but the top few machine tool builders from undertaking the necessary effort. For the typical machine tool builder, with annual sales of about $7 million, mounting even a small research and development effort is prohibitive.

Detailed information on the critical technologies is provided below:

CRITICAL TECHNOLOGY:
Electronic Controls

DESCRIPTION:
Electronic controls are used to command and control the motions and functions of machine tools. These controls may be relatively sophisticated Computer-based Numerical Controls (CNCs) which use numerical part programming information to command the machine, or Programmable Logic Controls (PLCs) which utilize electronic components to effect the sequential control logic previously provided by electromechanical relays.

WHY IS IT A CRITICAL TECHNOLOGY:
In order to meet the demand for increased machine versatility and to efficiently produce parts having complex shapes and/or close tolerances, which are increasingly used in aerospace, defense and consumer products, it is necessary that the machines producing these parts be electronically controlled. Such controls eliminate the variability and inefficiencies associated with human control of machines. The increased emphasis on product quality also dictates use of electronic controls that allow the manufacture of parts with close part-to-part consistency.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD (RoW):

		Lag	Par	Lead
J = Japan	1990	J, E		
E = Europe	2000	J, E		

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
Although the concept of numerical controls was created in the United States and further developed at MIT in the early 1950s, the dominant supplier of such equipment today is Fanuc of Japan, which accounts for over 70 percent of the world market. As a result of this and the fact that the Japanese government subsidizes considerable industrial research conducted in their country, the United States will have a hard time regaining the lead it once enjoyed. Recently the Japanese have exploited the U.S. developed capability which allows user-friendly programming of complex parts right at the machine.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Electronic controls are technologically dependent upon advances made in the semiconductor and computer industries. The emerging popularity of 32-bit Central Processing Units (CPUs) has decreased their cost to both computer manufacturers and to suppliers of electronic controls for production equipment. This development has in turn allowed the design and development of electronic controls having both increased functions and speed.

CRITICAL TECHNOLOGY:
Sensor Technology

DESCRIPTION:

Sensors are devices that provide an indication of force, displacement, power, temperature, or other process variables. They typically provide inputs to the electronic controls used to control a production process or piece of equipment.

WHY IS IT A CRITICAL TECHNOLOGY:

The control over a manufacturing process is a function of the degree to which process variables can be measured and of the relationship between these process variables and the attributes of the finished part. Because of this, sensor technology is critical to the efficient production of close tolerance parts. Of critical importance is not only the technology of the sensors themselves, but also the technology of signal processing and communication related to the sensor output.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990	J, E		
2000	J, E		

The United States lags the Europeans in the technologies associated with measurement of vibration, noise and displacement. It lags Japan in the technologies associated with solid-state video imaging.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:

The U.S. machine tool industry is dependent upon others for much of the sensor technology it uses. Many of these suppliers are foreign firms. No U.S. firm is large enough or profitable enough to undertake by itself a research program of sufficient scope to compete with any of the foreign companies who have well-established footholds in these areas.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:

In many cases the critical element of a sensor is made of semiconductor material, thus there is a dependence of the sensor industry upon the semiconductor industry. This dependence extends to the devices used for sensed signal conditioning for signal conversions, and for sensed signal mixing and decoding.

CRITICAL TECHNOLOGY:
Software

DESCRIPTION:
Software is the collection of programmed instructions used to define the responding, controlling and communicating functions of computer-based engineering and manufacturing equipment and systems.

WHY IS IT A CRITICAL TECHNOLOGY:
Software defines the responding, controlling and communicating functions of manufacturing equipment, it is critical in determining the capability and efficiency of the equipment being controlled. (An even more critical first-step is having a clear understanding of the process to be controlled.)

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			J, E
2000		J, E	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
The United States has been a recognized leader in software programming expertise. This exists primarily because electronic computers were first developed in the United States, and the installed base of computers, both main-frame and personal, is much larger here than in any other country. The rest of the world is rapidly catching up with the United States, as evidenced by the increasing number of Computer-Aided Design (CAD) systems available from overseas suppliers and by the increasing number of user-friendly features being added to Computer-based Numerical Controls (CNCs) produced abroad.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
As noted above, being able to efficiently program computer-based systems can only be done once the process to be controlled is sufficiently understood. Thus, the development of "good" software requires a background in manufacturing engineering, process engineering, and mathematics as well as a good background in computer programming. In effect, continuing state-of-the-art expertise in software is dependent upon continually updated experience and/or education in all of the aforementioned fields.

CRITICAL TECHNOLOGY:
Artificial Intelligence

DESCRIPTION:

Artificial intelligence as applied to manufacturing is that branch of science devoted to computer control of a product or a process using algorithms, logic and/or cause-effect relationships which might otherwise exist in the mind of a human operator or process designer.

WHY IS IT A CRITICAL TECHNOLOGY:

Artificial intelligence has the potential to significantly improve the productivity of manufacturing operations by incorporating human experience and/or human thought processes in the control regimen. As such it has the potential to improve the competitiveness of those businesses which employ it.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			J, E
2000		J, E	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:

The United States has pioneered efforts to develop artificial-intelligence technology particularly as it relates to manufacturing and/or the organization of data bases. It is anticipated, as a result of international interest in the subject, that competitive advances in this field will come from around the world and will not be limited to those made by U.S. investigators.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:

The utilization of artificial intelligence techniques, as is the case with the development of manufacturing-related software, is dependent upon a knowledge of both the manufacturing processes to be controlled and the science of artificial intelligence. A strong background in both manufacturing and in computer science is required.

CRITICAL TECHNOLOGY:
Laser Technology

DESCRIPTION:
Laser technology is the use of narrowly-focused light beams for measurement, and processes requiring the discrete application of heat.

WHY IS IT A CRITICAL TECHNOLOGY:
Possessing a continually updated inventory of state-of-the-art laser technology is critical to U.S. manufacturers because it can profitably be applied to such varied manufacturing tasks as measurement, cutting, joining, marking, etching, surface finishing, scribing, hole cutting, deburring, heat treating, chip breaking, etc. Indeed, many aerospace and commercial parts could not be economically produced without the use of laser technology.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			J, E
2000		J, E	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
It is known that the Japanese have for some years had a program to develop a manufacturing system utilizing a high-powered laser and a split-beam delivery system. This and other Japanese and European research endeavors will challenge the leadership currently enjoyed by the United States in laser technology.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Laser technology is dependent upon precision turning and finishing technologies for mirrors, and on optics and fiber-optics technologies for other aspects of the beam-delivery systems.

CRITICAL TECHNOLOGY:
Physics of Materials

DESCRIPTION:
The physics of materials relates to the measurable properties and characteristics of materials. For manufacturing, these properties are primarily those that relate to how the material cuts, bends, shears and welds.

WHY IS IT A CRITICAL TECHNOLOGY:
In order to produce a manufactured part, it is necessary to design an efficient process to create that part. In order to design the process, it is critical that one understands the physical characteristics of the material of the part, and especially how the characteristics of the part and the selected tool(s) will interact.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		J, E	
2000		J, E	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
For a number of years the U.S. manufacturing engineers have maintained a wealth of data showing what feeds and speeds should be selected for the efficient production of parts produced by metal cutting techniques. These data were available for a variety of combinations of workpiece materials and tool materials. With the advent of new tool materials (such as coated carbides, ceramics and Cubic Boron Nitride (CBN) materials) the previously published data are no longer sufficient. Research and/or lab tests to establish appropriate feeds and speeds for workpieces made of newer alloys and for tools made of new materials must be developed.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
The magnitude of the project to develop new feed and speed information is a function of the rapidity with which new alloys are developed by the primary metals industry and how fast tooling manufacturers develop new materials and/or coatings for tooling. It is likely that the need for the development of information on the physics of new materials (for both workpieces and tooling) will be forever ongoing as new materials continue to be developed.

CRITICAL TECHNOLOGY:
Advanced Materials Technology

DESCRIPTION:

Advanced materials include those not considered primary metals or their common alloys. They include metal matrix composites, graphites, fiber glass, ceramics and other man-made materials.

WHY IS IT A CRITICAL TECHNOLOGY:

Many industries require the use of special materials capable of withstanding the rigors of unusual environments. These industries include the aerospace and supersonic transport industries, nuclear industry, undersea exploration industry, petrochemical industry, etc. These industries require parts manufactured from materials capable of withstanding severe temperature, pressure, nuclear bombardment, corrosive, and similar environments. In order to retain our lead in the industries requiring these types of parts, it is necessary that we retain our lead in advanced materials technology.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		J	E
2000	J	E	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:

While the United States currently leads in advanced materials technology, this lead could be eroded by ignoring the research being pursued by firms in other countries including Japan, West Germany, France, Great Britain and Israel. The United States needs to be aware of and know the properties of these advanced materials in order to design and offer machines capable of producing parts made of such materials. The industry also needs to be aware and take advantage of the characteristics of these advanced materials when selecting the materials to be used in all newly designed machine tools.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:

The U.S. machine tool industry depends upon other industries for the development of these advanced materials and must work closely with them in order to minimize the time delay between the availability of advanced materials and the availability of manufacturing equipment capable of processing and/or utilizing those materials.

CRITICAL TECHNOLOGY:
Advanced Precision Bearings

DESCRIPTION:

Advanced precision bearings are used in machinery and technical products where there is a high demand for accuracy and reliability. Applications in jet engines, navigation devices and precision machine tools are typical.

WHY IS IT A CRITICAL TECHNOLOGY:

Modern machine tools require bearings of high geometric accuracy and low mechanical wear over time. Jet engines also require advanced precision bearings because of the necessary tolerance for high temperatures.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990	J	E	
2000	J	E	

Precision bearing races are especially ground, checked and paired together. Many state-of-the-art bearings come with ceramic balls for longer life and increased accuracy. Ceramic bearing technology is relatively new and only a few countries -- Japan, West Germany and the United States -- have that capability. Japan has a considerable lead over the United States.

THREATS TO U.S. RETAININC/GAINING PROMINENCE IN TECHNOLOGY:

The main threat is that these bearings are available from Japan at competitive prices. Their usage has been relatively low and U.S. suppliers have not been eager to adopt this technology.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:

Advanced precision bearing technology and especially ceramic bearing technology is dependent on the development of quality ceramic materials resistant to heat-induced cracking, and the availability of equipment to machine them. Here again, Japan has a considerable lead over the United States resulting from their previous work on ceramic rotors for automotive turbochargers and their research and experimental work on developing components for the so-called "adiabatic engine."

CRITICAL TECHNOLOGY:
Metrology

DESCRIPTION:
Metrology is the science of measurement and comparison of these measurements to an established system of references. Metrology is used extensively in manufacturing industries and especially in the machine tool and related industries.

WHY IS IT A CRITICAL TECHNOLOGY:
Present day technical products require accuracies unheard of a few years ago. The established "rule of thumb" requires that measuring instruments be at least ten times more accurate than the tolerance on the measured value. This necessitates the use of such technologies as optics, fiber-optics, laser beams, microelectronics, computers, etc. Without well-founded metrology principles and the associated precision instruments, the United States would be incapable of manufacturing the precision parts required for contemporary products.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990	J,E		
2000	J,E		

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
U.S. research and innovation in this area has been lagging behind that of Japan, West Germany and Switzerland. While in the past, Germany was at about the level of the United States, it continued with its thrust toward better, more complex measuring instruments. Japan has made great strides over the last 10-20 years, and is today neck and neck with West Germany.

While the United States still maintains equality in the theoretical field, regaining superiority in the commercial metrology industry will take substantial investment in manpower and capital.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Future advances in metrology may be fueled by new developments in fiber-optics, opto-electronics and high speed microcomputers. There is renewed interest sparked by the drive for product quality throughout the manufacturing sector, including the machine tool industry.

CRITICAL TECHNOLOGY:
Dynamics of Structures

DESCRIPTION:

The dynamics of structures is a scientific discipline based on the fundamentals of the strength and elasticity of materials. This science focuses on the minute elements of a structure, analyzing its behavior when subjected to a given set of external forces.

WHY IS IT A CRITICAL TECHNOLOGY:

Mechanical structures deform when subjected to external forces, such as those incurred by a machine tool. It is advantageous if the resulting deformation can be calculated and if steps can be taken to either minimize it or to use it as an advantage. Although the fundamentals of the dynamic behavior of structures have been known for some time, modern day computers have made possible comparisons between different structures subjected to a given set of forces. By using a technique known as "finite element analysis," one can predict the static and dynamic behavior of such structures and undertake countermeasures by either redesigning the structure or by rearranging the applied forces.

This technology makes it possible to design superior structures, be they machine tools, aircraft, automobiles, bridges or any other complex product.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990			J,E
2000		J,E	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:

The United States acquired prominence in this field at the time of the first mass introduction of powerful commercial computers. Lately, however, several industrialized nations have caught up with the United States. Japan, West Germany, Great Britain, Italy and even smaller countries like Belgium and the Netherlands are becoming world players in this discipline.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:

Computer technology plays a major role in this field. Proficiency in the use of computers and availability of the related software are of the utmost importance.

CRITICAL TECHNOLOGY:
Metallurgy

DESCRIPTION:
Metallurgy is the science of production and use of metals. It includes several disciplines, such as the extraction of metals from the ore, purification of the extracted metals, and their alloying, heat treatment and testing.

WHY IS IT A CRITICAL TECHNOLOGY:
Modern high-technology metals are exposed to a variety of environments, such as high temperature in aerospace engines. Another key application for specialty metals is in hostile environments, such as highly corrosive environments, chemically aggressive environments, mechanically abrasive environments and the like. The rotor blades of the gas turbine portion of a jet engine are heavily stressed by centrifugal force and are subjected to thermal stress as well as to mechanical abrasion from ingested debris. In some applications, the requirement is based on the light weight of the metallic components and this is where light alloys come into play. In machine tools, the emphasis is on structural integrity, resistance to wear of moving parts and suppression of vibration induced by the cutting or on inertia forces due to the cycling of the machine.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		E	J
2000		J,E	

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
This is one of the areas where the United States once had overwhelming international superiority, some of which still exists. Much of this technology was first developed by the automotive industry and later by the aerospace industry, including NASA. Over the last several years, foreign auto manufacturers have at least caught up with the United States. The European "Airbus" consortium has made great strides in civilian aircraft technologies, including metallurgy. In addition, Japan is planning to develop a fighter plane based on the U.S. F-16. It is almost certain that they will learn some of the existing U.S. technologies. One of the factors working against future U.S. superiority in metallurgy is the fact that in the United States emphasis has shifted from metals to other man-made materials such as plastics, carbon fiber and different high-tech composites.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
There is a high degree of competition between metallic materials and the newly developed high strength composites. In the automotive industry, plastics are replacing metal parts. All this directly affects the amount of funds budgeted for metallurgical research, chipping away at the historic U.S. preeminence in this field.

III. Threats to U.S. leadership in the Critical Technologies

Technological leadership requires a financially healthy industry, with the resources to invest in new products and processes. Financial health will only come with an internationally competitive industry that is free to pursue opportunities worldwide in the now global machine tool market. The U.S. industry does not maintain competitive footing in many markets, resulting in lost sales, and lost opportunities for customer driven innovation.

Factors inhibiting the ability of the U.S. industry to muster the resources required to actively pursue the research and development of critical technologies include:

- Small size and family ownership have reinforced a pattern of fragmentation and slow model-production changes. This, in turn, has contributed to limited resources for reinvestment and research, few links to university research joint projects, and often limited efforts to develop new products. Although many U.S. firms have a strong technical footing, because of their small size they have difficulty sustaining systematic long-term R&D efforts.[13]

- The extreme business cycles that characterize the industry also work against systematic investment in R&D. Dramatic shifts in demand for machine tools result from the multiplier effects of machine tool customers' orders and cancellations in response to their own business cycles. The cyclical nature of the business has resulted in volatile cash flow, problems in recruiting and retaining skilled technical people and a tendency to backlog orders to cushion against cyclical market forces.[14]

- U.S. export control policy is characterized by intransigence and delay. Uneven interpretation, administration and enforcement of COCOM's multilateral export control regime, in comparison with our allies, has seriously damaged U.S. machine tool exports. Not only does the U.S. Government enforce the rules more rigorously than its allies, it has refused to update the machine tool control list for 16 years. Largely as a result, in 1988 the United States exported just $1.3 million of machine tools to the Soviet Union. In the same year, West Germany exported $568 million worth of machine tools to the Soviets, and Japan exported $122 million.

- U.S. tax laws are biased against savings and investment and provide inadequate capital cost recovery. The 1986 Tax Reform Act's elimination of the investment tax credit and creation of a new Alternative Minimum Tax (which decelerates depreciation and increases the tax burden of marginally profitable, capital-intensive firms) have increased the cost of capital for America's machine tool industry and its customer base. While the United States decelerated depreciation schedules, other nations accelerated depreciation schedules and therefore stimulated investment.

- The U.S. product liability system, which is characterized by uncertainty, high transaction costs and lack of uniformity, unnecessarily burdens U.S. manufacturing firms. In 1988, the median machine tool builder spent seven times more on product liability than it did on research and development.

U.S. competitiveness in the critical technologies is also confronted by the large pool of resources foreign governments provide to ensure their domestic machine tool industry's leadership, particularly Japan and West Germany:

- During the 1950s, the Japanese government did not support any indigenous R&D projects, but controlled the flow of technology licensing agreements into Japan. Beginning in the early 1970s, government policy focused on broad subsidization of R&D through tax breaks and direct aid, and sponsorship of a number of specific projects. The government allocated $60 million to a cooperative effort to develop FMS, and once the basic technology was widely available, focused on financial assistance for installation. Although no specific figures are available, it is estimated that direct Japanese government expenditures for the machine tool industry has been approximately $500 million, and total assistance could be as high as $1 billion. More recently, the government has taken the leading financial role, committing to underwrite $400 million of a $1 billion 10 year international R&D effort on intelligent manufacturing systems.

- The European Community offers direct research and development assistance to individual companies through its BRITE, EUREKA and ESPRIT programs.

- The West German government has encouraged broad cooperation in R&D, training, setting of standards, and sales and service support in foreign markets. Contract research has been performed at eight major technical institutes, providing research that small companies could not undertake on their own. Individual firms have been able to obtain funding for their own research projects, if they published the results within two years of completion. The government has also helped to channel bank funds to specialist producers for their expansion efforts, and has strongly promoted trade within the Eastern Bloc.

- Canada, the United Kingdom, Italy and Japan heavily subsidize foreign buyer visits to their countries. Visits to the United States are funded entirely by the foreign visitor.

- Canada, France and the United Kingdom heavily subsidize foreign trade missions to promote exports. The United States does not.

Currently, certain U.S. machine tool products (lathes, machining centers, milling machines, and punching and shearing machines) are covered by a Voluntary Restraint Agreement (VRA) with Japan and Taiwan, instituted in 1987. The agreements are scheduled to expire in December of 1991. If the VRA is ended in 1991, foreign competitors are likely to reassert their pre-1987 domination of the U.S. market.

IV. Factors Supporting U.S. Leadership in the Critical Technologies

The United States is still near the top in terms of world machine tool consumption. This large domestic market could be the basis for the U.S. machine tool industry regaining leadership in the industry's critical technologies. Strong relationships with its customer base, in such areas as simultaneous engineering, could result in a symbiosis which would raise the competitiveness of both the machine tool industry and its customers.

A number of public policies have had some positive impact on the competitiveness of the U.S. industry. But many of the programs are not intended to directly help the machine tool industry.

The support to U.S. industry pales in comparison to that provided the machine tool industries of Europe and Japan:

- The National Center for Manufacturing Sciences (NCMS) was established in 1986. It is funded by membership fees and government grants. Its mission is to provide research support to the community of U.S. manufacturers in order to enhance their competitive position. A primary means of providing support is through the sponsorship of R&D activities which are critical to the advancement of state-of-the-art manufacturing technology.

- The Small Business Innovation Research (SBIR) program, administered by the U.S. Small Business Administration and established in 1982, is authorized through FY 1993. The program provides Phase I awards of up to $50,000 for evaluation of the technical merit and feasibility of ideas of potential use to businesses having fewer than 500 employees. Follow-on awards are possible.

- The U.S. Department of Defense Manufacturing Technology program (MANTECH) has the potential for addressing some of the research needs of the machine tool industry, provided there is significant direct participation by machine tool companies in the development and diffusion of new technologies. The Air Force, which was involved in the development of numerical controls in the 1950s, has recently shown interest in such participation. There is also a potential for significant DARPA participation in machine tool research and development projects.

- The National Institute for Standards & Technology (NIST) for several years has funded, directly or with help from the U.S. Navy, work at the Advanced Manufacturing Research Facility (AMRF) whose function is to help develop manufacturing standards applicable to the machine tool industry.

- The National Science Foundation (NSF) provides research awards. In recent years, awards relating to manufacturing technology projects have increased. Research into high speed milling, grinding, process simulation, analysis of machine structures and robotics has been augmented by NSF funding.

- The U.S. Congress has modified the R&D Tax Credit so it is more usable by small, slow-growth companies, such as many U.S. machine tool builders.

- The United States currently has the lead in the emerging artificial intelligence and expert system technologies. However, West Germany and Japan are rapidly catching up.

Other Opportunities for the U.S. Industry

- Regrowth of U.S. supplier base is necessary to secure the products necessary to build U.S. machine tools.

- Export potential exists, particularly to the newly industrializing countries, Europe, the Soviet Union and Central Europe.

- U.S. industry must find a way to apply high-tech inputs (CAD, CNC, etc.) to small companies that cannot afford, let alone understand, electronic inputs. Drawings on paper are becoming increasingly obsolete.

FOOTNOTES

1. March, Artemis, "The U.S. Machine Tool Industry and Its Foreign Competition, " in The Working Papers of the MIT Commission on Industrial Productivity, Vol. 2, Cambridge, MA, MIT Press, 1989, p.2.
2. 1987 Census of Manufacturers, "Metalworking Machinery and Equipment," MC87-1-35C, Bureau of the Census, Washington D.C., 1990, p.35C-8.
3. March, op.cit., pp.9-10.
4. Ibid., p.3.
5. Ibid.
6. Ellison, John N., et al, Mobilizing U.S. Industry: A Vanishing Option for National Security?, Boulder, CO, Westview Press, 1988, p.39.
7. Harvard Business School, "The Machine Tool Industry and Industrial Policy 1955-82," Boston, MA, Publishing Division, Harvard Business School, 1987, p.1.
8. March, op.cit., pp.5-6.
9. Ibid.
10. Ibid., p.14.
11. Ibid., p.15.
12. Ibid.
13. Ibid., pp.10-11.
14. Ibid., pp. 11-12.
15. Harvard Business School, op.cit., pp.26-27.
16. Ibid., pp.29-30.

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

The Council would like to thank the staff of NMTBA/The Association for Manufacturing Technology for preparing this profile.

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ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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A COMPETITIVE PROFILE OF THE
MOTOR VEHICLE INDUSTRY

Research Paper for

GAINING NEW GROUND:
TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future*.

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling.

SECTORAL PROFILE: THE MOTOR VEHICLES AND EQUIPMENT INDUSTRY

EXECUTIVE SUMMARY

Key Points

- The Motor Vehicles and Equipment industry is the largest U.S manufacturing industry, employing about 850,000 people.

- Producing an automobile is a highly complex process, involving producing and assembling about 15,000 parts. As a result, many skills and technologies are critical to the industry.

- The industry is an important end-user of many materials and components, and is thus an important market for many technologies.

- Imported cars and U.S.-built cars by foreign manufactures have been capturing an increasing percentage of the U.S. automobile market. Imported cars represented 28.5 percent of the U.S. market in 1989.

- The industry's trade deficit in motor vehicles and equipment is over $50 billion and represents about 40% of the total U.S. trade deficit. The automotive trade deficit with Japan is about half of the automotive trade deficit. This deficit is forecast to continue or expand as Japanese automakers compete in more expensive cars and trucks.

- U.S.-based automobile production is increasingly competitive, as U.S. automakers have rapidly improved their quality and Japanese automakers have begun to produce in the United States.

- U.S.-owned automobile production remains competitive internationally. GM and Ford are the world's number 1 and number 2 automakers, and the overseas production by U.S.-owned companies exceeds the U.S. automotive imports.

- Current trends are towards increasingly global operations, improving quality and productivity, streamlining operations, reducing time to market, developing closer relationships with suppliers, and improving technologies in response to environmental pressures.

- Technology comes into the industry from a variety of sources, including R&D by manufacturers, automotive parts suppliers, and suppliers from other industries. The industry spent 3.6 percent of sales on R&D (mostly "D") in 1989.

Critical Technologies

A large number of technologies are important to the industry. At a systems level, the following are important:

- **Powertrain Systems**, including more fuel efficient, lighter, lower emission, and alternative fuel engines, electric motors and drives, and 2-stroke engines.

- **Electronic systems**, including electronic controls for mechanical systems, multiplex wiring, and various features, such as information, navigation, safety, anti-theft, diagnostic, and entertainment systems.

- **Manufacturing systems**, including the integration of design, manufacturing and R&D functions; the design of the material and information flows; and the integrated control of production operations.

In each of these systems there are many critical enabling technologies, including:

- **Electronic components and controls**, including various microelectronic components, software, sensors, optoelectronics, and actuators.

- **Powertrain technologies**, including variable valve timing, tribology, catalysts, combustion research, and electrical storage technologies,.

- **Materials** for powertrains and car bodies, including polymer and metal matrix composites, high strength and coated steels, engineering plastics, ceramics, and titanium, magnesium, and rapidly solidifed aluminum metals.

- **Process technologies**, such as flexible computer integrated manufacturing, flexible high speed machining, machine intelligence and intelligent robots, stamping, various materials processing technologies, laser welding, and adhesive bonding.

- **Environmental technologies**, including recycling/waste management, technologies for reduced manufacturing emissions.

- **Design and Engineering Technologies** such as computer modeling and simulation (computer aided engineering), high speed computing, expert systems, integration of design/prototyping/manufacturing processes, systems engineering, human factors studies, neural networks, and high level software languages.

Threats to U.S. Leaderships in Critical Technologies

- Historic low priority of manufacturing engineering.

- Weaknesses in commercializing technologies and long product cycles.

- Potential weaknesses in related industries.

- External and internal barriers to long term investments.

- Lack of constructive relations with DOT and EPA.

- Lingering antitrust distrust.

Factors Supporting U.S. Leadership in Critical Technologies

- Globally strong U.S. companies.

- Strong technical capabilities in domestic manufacturers.

- Large domestic market.
- U.S. companies are rapidly learning from foreign manufacturers.

I. INDUSTRY CHARACTERISTICS

Industry Definition and Size

The most standard definition of the industry is the Department of Commerce's SIC 371 Motor Vehicles and Equipment, which consists of Motor Vehicles and Car Bodies, Truck and Bus Bodies, Truck Trailers, Motor Homes, and Motor Vehicle Parts and Accessories. (1) In addition, some other industries that do not fall within SIC 371, are also considered motor vehicle parts and accessories.

The motor vehicle industry is the largest manufacturing industry:

- The value of shipments for SIC 371 (Motor Vehicles and Equipment) was $189 billion (1986).(2)
- The employment for SIC 371 was 850,000. Many others are employed in manufacturing automotive components which are classified in other industries.

The industry produces very complex products -- a typical motor vehicle has about 15,000 parts.(3) Because of this, every auto manufacturer must manage processes of vast complexity and must master many skills and technologies.

Industry Structure

The U.S. market is highly concentrated. The U.S auto industry is dominated by the "Big Three" -- General Motors (GM), Ford, and Chrysler. Internationally, the top eight automakers have about 70% of the world market.(4)

U.S. producers no longer include only the big three, as several Japanese automaker have established factories in the United States. By 1993, "New American Manufacturers" (NAMs), will include Honda, Toyota, Nissan, Mazda, Diamond Star (Mitsubishi-Chrysler),, Fuji-Isuzu, NUMMI (Toyota-GM) and Hyundai (in Canada). They will have a total car and light truck production

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1 U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook - 1990, Washington, U.S. Govt. Print. Off. 1990, p. 38-1. The latest year for which the U.S. Industrial Outlook has figures for SIC 3711 is 1987.

2 Motor Vehicle Manufacturers Association, Motor Vehicle Fact and Figures '89, Detroit, July 1989. p. 66. This uses data from the Bureau of Census' Annual Survey of Manufacturers.

3 Womack, James P. "The U.S. Automobile Industry in an Era of International Competition: Performance and Prospects," in The Working Papers of the MIT Commission on Industrial Productivity, vol 1. Cambridge, MIT Press, 1989. p. 1.

4 "The Business Week Global Auto Scoreboard," Business Week, May 7, 1990, p. 54-55.

capacity of 2.7 million vehicles, compared to 12.8 million vehicles for Ford, Chrysler, and GM.(5)

Automobile manufacturers vary in the degree to which they are vertically integrated. Of the U.S. companies, GM is the most integrated, with only 30 percent of the value of its cars coming from independent suppliers. Chrysler is the least integrated, with about 70 percent of the value of its cars coming from suppliers. Japanese automaker rely on suppliers even more, for about 75 percent of the value of the car, but Japanese automakers have close, long-term relationships, usually involving some equity ownership and a considerable degree of influence on their suppliers.(6) Japanese automakers also exert more control over their dealers, and can prevent them from selling other brands of cars, such as imports.

The manufacturer-supplier relationships are considerably different in the United States and Japan. A single U.S. assembly plant may deal with several thousands parts suppliers. A Japanese auto manufacturer is likely to deal with only 200-300 "1st tier" suppliers, who further subcontract to "2nd and lower tier" suppliers.(7) U.S. manufacturers are moving towards reducing the number of suppliers. Ford, for example now deals with only a thousand contractors.

Upstream Industries

Upstream from the motor vehicle manufacturers are the suppliers of materials, components systems, and process machinery.

Key upstream industries include:

- Motor vehicle parts
- Machine tools
- Iron, steel, aluminium
- Chemical and allied products
- Plastics
- Electronics

The motor vehicle industry is an important customer for many industries. Electronic components make up an estimated 10-15 percent of the value of cars, which indicates that the value of automotive electronics in the $10-20 billion range. (For comparison, the value of the U.S. consumer electronics market is

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5 Flynn, Michael S. and David J. Andrea, Capacity, Competition, and Change: the 1988/1989 OSAT Supplier Survey Respondent Report, June 1989, p 7,8.

6 Cole, Robert E, and Taizo Yakushiji, eds., The American and Japanese Auto Industries in Transition, Ann Arbor, MI, University of Michigan Center for Japanese Studies, 1984, p. 152.

7 Tanuma, Takeshi, "The Key to the Challenge, Black Box Engineering," UMTRI Research Review, September/October/November/December 1989, p. 10-11.

around $40 billion.) The motor vehicle industry also accounts for a significant percentage of the U.S. consumption of many materials.

Material	1987 Motor Vehicle Percentage of U.S. Consumption
Steel	14.8%
Aluminum	15.7
Copper	10.2
Lead	54.5
Malleable Iron	43.0
Platinum	39.5
Synthetic Rubber	46.5

Source: MVMA, Motor Vehicle Facts and Figures '89, p. 72.

There are many suppliers to the industry. They supply components and systems as diverse as tires, stereos, and upholstery and range from large, technically sophisticated companies like TRW, Goodyear, and Dupont, to small companies that have little technical sophistication.

Suppliers are critical to the competitiveness of an automobile company. In the past, manufacturers chose suppliers primarily based on price, and made and broke relationships with suppliers based on price. Recent trends have been for manufacturers to develop more cooperative relationships with suppliers, and to give higher priority to criteria other than price, such as quality, delivery capability, and engineering competence.(8) This is moving closer to the Japanese model of manufacturer-supplier relationships.

Downstream Industries

Downstream from the motor vehicle industry are dealers, customers, and the motor vehicle accesories and services industries. These are quite large industries. In 1986, automotive sales and servicing employed over three million people.(9) Road construction, petroleum refining and distribution, and trucking are other closely related industries.

Relationship to National Defense

Many of the critical technologies for the automobile industry, such as electronics, advanced materials, and manufacturing skills, are "dual-use" technologies that have both military and civilian applications. Some Department of Defense-funded research and development in these areas is relevant to the automobile industry. U.S. automakers have been defense contractors to varying

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8 Flynn, Michael S. and David J. Andrea, Capacity, Competition, and Change: The 1988/1989 OSAT Supplier Survey Respondent Report, Ann Arbor, MI, University of Michigan Transportation Research Institute, June 1989, p. 20-21.

9 Motor Vehicle Manufacturers Association, Motor Vehicle Fact and Figures '89, Detroit, July 1989. p. 67.

degrees, but a perhaps more important connection is through the broad base of suppliers that the automakers and DOD share.(10) Automakers have found it difficult, however, to apply technologies developed for defense, even by their own subsidiaries, to their automobile operations. These difficulties are largely because many defense technologies are not appropriate for the high volume, low cost, high reliability needs of the automobile industry.(11)

Competitive Position of the U.S. Motor Vehicle Industry

By most common measures, the motor vehicle industry has had significant competitive problems in the last two decades. The large trade deficit in automotive goods (vehicle and parts), which has been about 40 percent of the total U.S. trade deficit in recent years, is the most obvious indicator of those problems.

U.S. Trade Balance in Vehicles and Parts
(billions of current dollars)

Year	Trade Balance	Trade Balance with Japan
1978	-10	-6.0
1980	-12	-10.5
1982	-18	-11.9
1984	-33	-17.4
1986	-57	-31.9
1988	-59	-27.7

Source: Flynn, Michael S., Sean P. McAlinden, and David J. Andrea. The U.S.-Japan Bilateral 1993 Automotive Trade Deficit, Ann Arbor, University of Michigan Transportation Research Instititue, September 1989. p. 58-59.

The trade balance in automotive parts and accessories, which is largely included in the statistics above, is also negative, but is better balanced than that for motor vehicles as a whole. In 1989, imports were $19.9 billion, while exports were $15.9 billion.(12)

The import share of the U.S. automobile market has been increasing steadily since the mid-1960s. This share has leveled off and shows signs of decreasing as foreign-owned manufacturers have set up manufacturing facilities in the United States.

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10 Lewis Branscomb makes the point that the common suppliers are a key link between commercial products and DOD products.

11 Norman Gjostein of Ford, telephone interview, July 1990.

12 U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook, 1990, Washington, U.S. Govt. Print. Off., 1990. p. 38-7. Data is for Automotive Parts and Accessories, SIC 3465, 3592, 3647, 3691, 3694, and 3714.

Import Share of the U.S. Automobile Market

Year	Import Share	Japanese Share
1955	0.8	
1960	7.6	
1965	6.1	
1970	15.2	3.7
1975	18.2	9.4
1980	26.7	21.2
1985	25.7	20.1
1989	28.5	20.3

Source: Motor Vehicle Manufacturers Association, 1st Quarter 1990 Economic Indicators, Detroit, May 1990. p. 4. (13)

While Japan dominates the percentage of vehicles sold in the United States, they have been concentrated at the low end of the market, which has traditionally been unprofitable for the American manufacturers. European imports have been more at the high end of the market, which has traditionally been the most profitable part of the market for U.S. producers.

It can be noted that the United States does not import an excessively large number of cars, but that the trade deficit comes from a lack of exporting. The lack of exports is partly because Ford and GM produce many of their cars for foreign markets in overseas plants. Overseas sales and production of cars by U.S. companies slightly exceeds U.S. imports of cars.

The U.S. share of world motor vehicle production declined dramatically in the 1960s and 1970s, but has leveled off in the 1980s.

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13 Figures for 1955-1965 come from Womack, op. cit. p. 2.

U.S. Share of World Motor Vehicle Production

Year	Percent
1965	45.9
1970	28.3
1975	27.2
1980	20.8
1985	26.0
1988	23.2

Source: MVMA, Motor Vehicle Facts and Figures '89, p. 72.

Japan overtook the United States as the world's leading producer in 1980, but the United States and Canada together, which constitutes a single automobile industry, still produce more vehicles than does Japan. The global competitive position of the U.S.-owned automobile industry is still fairly strong, with GM, Ford, and Chrysler being the first, second, and sixth largest automakers in the world, respectively.(14)

The U.S. industry, on the average still lags behind Japan in assembly productivity, although the best North American plants are better than the average Japanese plant. The data below should be interpreted with some caution. Assembly is only a small part of the total effort that it takes to make a car. The figures shown here are adjusted to attempt to compensate for the fact that cars differ in the amount of work they require (large cars with more options generally require more work than small cars). Although some of Europe's automakers, such as Mercedes, require a relatively large number of hours to produce a car, because the product is highly valued, the amount of value-added per worker hour is still high.

Assembly Plant Productivity By Region, 1989, (hours)

Companies	Japanese Companies in Japan	U.S. companies in North America	European in Europe
Best	13.2	18.6	22.8
Average	16.8	24.9	35.5
Worst	25.9	30.7	55.7

Productivity here is the hours of effort, (management and hourly, direct and indirect) needed to accomplish the standard manufacturing activities on the standard vehicle in plants running at full output.

Source: Womack, James P., Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, New York, Rawson Associates, 1991, p. 85.

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14 "Business Week Global Auto Scoreboard," Business Week, May 7, 1990, p. 54-55.

Reasons for the Loss of Competitiveness(15)

Industry analysts have blamed the decline of the U.S. automobile industry on a combination of several factors:

- Management dominated by financial people rather than engineering people, who were reluctant to make the long term investment in new products and processes necessary to improve the design and quality of cars.
- Unions that demanded compensation increases in excess of productivity increases.
- Unnecessarily burdensome government regulations that were applied with little consideration of the competitive needs of industry.
- Uncooperative and unproductive relationships between management, labor, and government that did not allow for solving problems in a manner that were in the long-term interests of the industry.
- A system of production and market strategy that was developed in the 1920s and worked until the 1960s but had disadvantages in the 1970s and 1980s relative to production systems developed in Japan and Europe.

In this last view, the U.S. system was based on the mass production of a limited number of types of automobiles, with variability provided by add-on options. To produce these large volumes of largely standardized automobiles, jobs were simplified, specialized, and standardized, so that members of both labor and management had narrowly but rigidly defined jobs. Production machinery was also adapted for specialized purposes and long production runs. Workers were expected to perform competently with the narrow boundaries of their job but were not expected to perform other functions or to try to improve their jobs. Workers and subcontractors were frequently laid off to compensate for slumps in demand.

Europe, with greater cultural and political diversity, developed many more types of cars, each of which had to be profitable with a smaller market base. Japan, with limited resources and a small and fragmented internal market after World War II, developed a production system that allowed for profitability with low volume production and with limited capital equipment. They developed flexible machinery that could rapidly be changed from one product to another, and a system that required low inventories of parts. In addition, the system Japan developed was based on constant improvement of all aspects of the product and production system, including improving products, improving quality, and improving productivity. A new set of labor-management relations, based on company unions and lifetime employment, were part of this system.

The European system led to the development of excellent cars for market niches that Detroit felt were too small to exploit, such as highly engineered luxury

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15 Material in this section comes primarily from Womack, op. cit. p. 9-24, and Womack, James P., Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, New York, Rawson Associates, 1991.

sports sedans. The Japanese system, with its constant improvement of both products and processes, led, over time, to high levels of quality and an ability to rapidly get new products to the market. It is perhaps the quality and reliability more than anything else that has contributed to the increase market share of Japanese imports.

Outlook

The competitive outlook for the U.S. motor vehicles industry is somewhat mixed. There are several positive trends. Much of domestic industry has made rapid improvements in quality in recent years, to the extent that some people believe that quality will soon no longer be an issue.

Defects Per 100 Vehicles

	1980	1986	1989
GM	740	338	162
Ford	670	285	143
Chrysler	810	326	178
European	270	307	204
Japanese	205	188	119

Source: Washington Post, January 3, 1990, citing Harbour and Associates, The Harbour Report: A Decade Later.

In a broader measure of quality, the J.D. Power Customer Satisfaction Index shows that U.S. cars have been improving relative to European and Japanese cars, but still lag behind Asian cars. (Satisfaction with the dealer influences this index, so it does not only reflect changes in product quality.)

Consumers Satisfaction Index

Origin	1985	1986	1987	1988	1989
North American	87	94	98	102	112
Asian	114	119	119	122	130
European	106	106	102	110	111

Source: U.S. Department of Commerce, International Trade Administration, U.S. Industrial Outlook, 1990, Washington, U.S. Govt. Print. Off., 1990. p. 38-3.

There is also evidence that productivity is improving among U.S. automakers.

Productivity Improvements

	Ford	Chrysler	GM	Japanese Transplants
Assembly				
workers per car per day	3.36	4.38	4.99	3.48
improvement 1979-1988	31%	17%	5%	(includes stamping)
Stamping efficiency improvement	45%	30%	14%	
Engine production efficiency improvement	43%	9%	-9%	

Source: Harbour & Associates, The Harbour Report: A Decade Later, Executive Summary.

From the perspective of U.S. based manufacturing, there are additional bright spots. The New American Manufacturers (NAMs), which are the U.S. based operations of foreign automakers and their joint ventures with American manufacturers, are also showing that the U.S. based production can produce high quality cars with high productivity. The NAMs are expected to export cars to both Japan and Europe.(16) While there is concern that the NAMs will increase the trade deficit in automotive parts, by importing a greater percentage for their components from Japan, the NAMs are manufacturing an increasing proportion of their components in the United States. Honda, for example has announced that it will produce 75 percent of the value of its American assembled products in the U.S. by 1991.(17, 18)

There are also several negative trends. From the point of view of American-owned production, the NAMs represent not only competition but also a cause of the 30% overcapacity in the industry that is likely to lead to intense competition, lower profits, and retrenchment. The movement of Japanese producer to the more expensive end of the market and to other market niches poses a new threat to the Detroit. For these reasons, some analysts the automotive trade deficit to be at least as large in 1993 as today.(19)

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16 Flynn, Michael S., Sean P. McAlinden, and David J. Andrea, The U.S.-Japan Bilateral 1993 Automotive Trade Deficit, Ann Arbor, MI, University of Michigan Transportation Research Institute. p. 41. They estimate NAMs could export as many as 230,000 vehicles by 1993.

17 Womack, op.cit., p. 7.

18 Flynn, Michael S., Sean P. McAlinden, and David J. Andrea, The U.S.-Japan Bilateral 1993 Automotive Trade Deficit, Ann Arbor, MI, University of Michigan Transportation Research Institute. p. 41. They estimate NAMs will contain no more than 75% local content to keep them as counted as part of the "imported" fleet for CAFE calculations.

19 Flynn, et al, op.cit. p. iii, iv.

As quality evens out, the focus of competition may shift to other areas, such as being able to quickly bring out new models to meet changing trends and to fill market niches, and technology. The U.S. industry lags behind the Japanese industry in the time it takes to bring new cars to market, and requires greater production volume for each car to be profitable.(20) There is also evidence that the U.S. position in technology is declining with respect to Japan and that there is a perception that Japan now leads in a number of emerging areas of technology. Patent data, although perhaps indicating a propensity to patent as much as anything else, provide a picture that is consistent with these trends.

Share of U.S. Motor Vehicle and Other Non-aircraft Patents Granted to Inventors of Various Countries

Country	1978	1988
United States	63.9%	43.3
Japan	14.5	25.8
West Germany	5.6	12.6
France	3.7	3.7
United Kingdom	3.7	3.7
Others	8.6	10.9
Total Number of Patents	2540	3159

Source: National Science Board, Science and Engineering Indicators - 1989, Washington, U.S. Govt. Print. Off. 1990, p. 362.

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20 Womack, op.cit., p. 25-26.

II. CRITICAL TECHNOLOGIES

Role of Technology

The direction of automobile technology is strongly influenced by the industry's perception of what customers want and by regulatory pressures. At times these regulatory pressures run contrary to consumer tastes (such as with seat belt/ignition interlock systems), while at other times consumer tastes and the regulatory requirements move in the same direction (such as fuel economy requirements during the oil crises).

In general, the industry has perceived that customers are not willing to pay a great deal for improved technology per se, but that customers want many characteristics that improved technology can help bring about. These include:

- Reliability, durability and serviceability
- Innovative exterior and interior styling and appearance
- Smooth and noiseless operation
- Power and acceleration
- Handling and ride quality
- Fuel economy
- Comfort, spaciousness, and convenience
- Safety

While any of these can be achieved using less than state-of-the-art technology, to improve on all of them requires increasingly advanced technology. Some of these features, such as fuel economy and safety, were once driven by regulatory requirements but are to some extent also a customer demand.

In addition to these market driven changes, regulatory pressures shaping the direction of technology include tightening CAFE requirements, tighter emissions requirements, and increasing problems in disposing of solid wastes, especially for plastics and composites.

Innovation Process in the Motor Vehicle Industry

The innovation process in the automobile is largely one of making incremental improvements to existing technologies. Most of the major systems in automobile have changed only slowly over many years.

Innovation occurs on several levels. Automakers are constantly introducing new or improved models of automobiles, each representing an incremental improvement over previous automobiles. In addition, innovation occurs in systems, components, and materials, and these innovation may be incorporated into in existing models of cars or introduced in new models. Finally, innovations are incorporated into new production processes, which involve changes in plant design as well as changes in production equipment.

Managing innovation on these different levels is difficult but critical. On the one hand, innovations in the product need to be integrated with process innovations. On the other hand, automakers have discovered that it is sometimes a mistake to do to much too quickly, such as building a new car in a new plant, because there are too many bugs to be worked out at once.(21)

A new car typically goes through a number of stages to get to market, including:(22)

1. Concept Study
2. Product Planning
3. Advanced Engineering
4. Product Engineering
5. Process Engineering
6. Pilot Run

Time --> 7. Marketing and Sales

Shortening the time to get a new car through this process is a key to competitiveness. A shorter time between a concept and the market allows the car to be closer to current consumer preferences and allows each car to have more current technology when it reaches the market.

U.S. car manufacturers currently lag behind the Japanese in the time it takes to get a new car to the market. A 1987 study by Kim Clark at Harvard indicated that the average Japanese auto company took 43 months to move a product from conception to the market, while U.S. and European companies took 62 months.(23) The same study indicated that U.S. and European companies use twice as many engineering hours to complete comparable projects. U.S. automakers have been working to shorten their time to market, largely by shortening each stage of the process and by increasing the amount of overlap and interaction between stages. Some believe that they have improved considerably, and are within twelve months of the Japanese level.24

New knowledge and technology comes into this process at many stages and comes from several sources. One source is the automaker's R&D programs and the expertise of its engineers. Another is the resources of its suppliers, which often bring their own technology to the automaker, or develop technology in cooperation with the automaker. Similarly, process technology may come from outside

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21 An illustration of the advantage of moving in small quick steps is that Honda, moving in several stages, was able to build a U.S. production base faster than GM's Saturn, which tried to do everything at once. White, Joseph B., "GM's Plan for Saturn, to Beat Small Imports, Trails Original Goals," Wall Street Journal, July 9, 1990, p. 1.

22 Womack, op. cit. p. 28-32, citing studies by Professor Kim B. Clark of Harvard Business School.

23 Ibid.

24 Comments from General Motors on a draft of this report.

suppliers or may be jointly developed with the automakers. In addition, automakers form technical alliances, joint ventures, and licensing agreements with competitors to acquire technologies.

The effort to improve quality requires that technologies be well proven before they are built into an automobile. This makes the innovation process more conservative and requires more rigorous testing of new products. Automobiles have to use proven, "off the shelf" technologies and the U.S. is relatively weak at getting advanced technologies "on the shelf".(25) The U.S. does relatively well in the basic research and initial innovation, but does relatively poorly in the advanced engineering and product engineering that is necessary to get the technology into commercial systems. Relative strength of Japan in this process is their close relations with their suppliers that allows manufacturers to rely on their suppliers for well tested components and systems.(26) U.S. automakers are also working to improve in this area.

Critical Technologies

The automobile industry uses a large number of technologies in its complex products and processes. For the most part, automobile manufacturers focus on the total automobile and on some critical systems, such as engines. Many other components and some subsystems are jointly developed with, and produced by, suppliers. Underlying these are the more generic and enabling technologies. For many of these technologies, the needs of the automobile industry do not push the state of the art in terms of the performance -- the aerospace and other defense industries often require materials and electronics that have higher level of performance. R&D in the automobile industry often focuses on adaptations of these technologies that are appropriate for the automobile industry, and on lower cost production methods.

The critical technologies for the automobile industry can be divided into product and process technologies. The following pages provide an overview of the key systems level technologies and the generic enabling technologies that they use, and then provide more detail on specific generic enabling technologies.27

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25 Tom Moore, Chrysler Corporation, personal interview, June 27, 1990.

26 Tanuma, Takeshi (President, Nissan R&D), "The Key to the Challenge, Black Box Engineering," UMTRI Research Review, September-October/November-December 1989, p. 10-11.

27 This list is based on information provided by, and discussions with Norman Gjostein of Ford Motor Company

Product Technologies:

Systems	Enabling Technologies
Powertrain	
High Fuel Economy/	Electronic Controls/Adaptive Controls
High Power Density Engines	Sensors
Multiple Valve Engines	Powertrain Materials
Variable Induction Systems	metal matrix composites
Turbo/Supercharging	polymer composites
Variable Valve Timing	ceramics
Low Emission engines	rapidly solidifed aluminum
Alternative Fuel engines	titanium alloys
Alternative Powertrains	magnesium
Electric Motors	Catalysts
2-Stroke engines	Tribology
Advanced Diesels	Electrical Storage Technologies
	Combustion Research
Suspension/Steering/Brakes	
Antilock Brake Systems	Advanced Materials
Traction Control	Electronic Controls
Computer Controlled Ride	Reduced Rolling Resistance Tires
Reduced Rolling Resistance	
Body	
Mass Reduction	Polymer Composites
Improved Occupant Protection	Aluminum Alloys
Improve Comfort	High Strength Steels
Increased Structural Stiffness	Coated Steels
Reduced Drag	Engineering Plastics
Improved Corrosion Resistance	Solar Glass
Electronics	
Information Systems	Electronic Materials, esp. Packaging
Navigation Systems	High Llevel Languages
Safety Systems	Optoelectronics
radar warning	Electronic Controls
infrared vision	microprocessors and ASICs
Entertainment Systems	control theory
Anti-theft Systems	software
Diagnostics	sensors
dealer and on-board	actuators
Multiplex Wiring Systems	Infrastructure for Communications/ navigation
wire, fiber optic	
Controls for Mechanical Systems (engine, steering, etc.)	Systems Engineering
Electronic Features	electronic systems architecture
voice actuation, memory seats	subsystem integration/interaction
Integrated Vehicle Controls	
Vehicle/Highway Interface Technologies	

Process Technologies

Area	**Enabling Technology**
Manufacturing	
	Architecture of Manufacturing (Material and Information Flows)
	Assembly process design
	Machining process design
	Integration of Design, Manufacturing and R&D functions
	Flexible, Computer Integrated Manufacturing
	Flexible high speed machining
	Integrated Control of Production Operations
	Sensory feedback
	Adaptive control
	Automation
	Machine intelligence and intelligent robots
	Neural networks
	Computer Modeling and Simulation
	AI/Expert systems
	Laser Welding
	Adhesive bonding
	Environmental Technologies
	Recycling/Waste Management
	Technologies for reduced manufacturing emissions
	Stamping
	Forming
Materials Processing	
	Net Shape Forming
	Precision Casting
	Polymer Composite molding
	Aluminum Forming
	Ceramic Processing

Design and Engineering Process Technologies

Design for Manufacturing/ Design for Assembly	Computer Modeling and Simulation
	Computer Aided Engineering
Product Program Management Process	High Speed Computing
	Expert Systems
	Integration of Design/Prototyping/Manufacturing Process
	Human Sensitivity Studies (objective measurements of subjective responses)

CRITICAL TECHNOLOGY: **Electronic Controls**

DESCRIPTION: Electronic control systems used in a variety of automobile systems, such as more fuel injectors, active suspension systems, etc. Electronic controls consists of computers or microprocessors, software, sensors and actuators.

WHY IS IT A CRITICAL TECHNOLOGY? Electronic controls can greatly improve the functioning of many systems, providing improve performance and greater efficiency.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

J=JAPAN
E=EUROPE

	Lag	Par	Lead
1990	J	E	
2000	J	E	

Japan and Europe are leading in the applications of electronic controls to some automobile systems, such as active suspensions.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Weaknesses in the U.S. electronics industry (see electronic components profile) and lack of cooperation between suppliers and manufacturers.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on advances in semiconductors, signal processing, software, sensors, actuators, on-board communications. "Signal processing" and "passive sensors" are on DOD's critical technologies list.

POLICY ISSUES: Federal R&D funding in related areas.

CRITICAL TECHNOLOGY: **Advanced Sensors**

DESCRIPTION: Sensors to monitor various conditions in automobiles and in manufacturing and materials processes. Includes electronic, optoelectronic, acoustic, and biological sensors.

WHY IS IT A CRITICAL TECHNOLOGY? Essential element of electronic control systems in many automotive systems, including engine, suspension, steering, braking, diagnostics, and emissions control systems. Also essential for control over many aspects of production and manufacturing processes to increase quality and productivity.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

J=JAPAN

E=EUROPE

	Lag	Par	Lead
1990		J,E	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Weaknesses in electronics industry could cause weaknesses in sensors.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on microelectronics, biotechnology, optoelectronics. Advanced sensors are essential for process monitoring and control. Passive sensors is on DOD critical technology list.

POLICY ISSUES: There is substantial (FY 91=$460 million) DOD funding of sensor technology, some of which may be useful to the automobile industry. Technology transfer from DOD/DOE labs; NSF funding.

CRITICAL TECHNOLOGY: Composites and Fabrication Technology

DESCRIPTION: Composites are combinations of two or more materials that make a new material with some of the properties of each component. They include inorganic (ceramic and metal matrix) and organic (polymer matrix) composites and related fabrication technologies. Composites for the automobile industry need to be ones that can be manufactured at low cost.

WHY IS IT A CRITICAL TECHNOLOGY? Composites can be lighter and stronger than the materials they replace, and thus can greatly improve the performance of many technologies, for example allowing more fuel efficient and higher performing automobiles. High manufacturing costs are current barriers to more widespread applications.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

		Lag	Par	Lead
Reinforcements = R	1990		R	C
Composites = C	2000			

Source: JTEC

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: U.S. is currently in a strong position in composites for use in the automobile industry. A more systematic, long-range approach to composite technology development in Japan could weaken the U.S. advantage. Airframe and aerospace industry has driven U.S. composite technology, but many of these composites are too expensive for use in the automobile industry.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Aerospace and motor vehicles are large markets that can drive the technology. Solid state chemistry, interface and surface science, supercomputers and modeling, and processing technology are critical related sciences and technologies. Automotive Advanced Composites Consortium, in which Ford, Chrysler, and GM are funding precompetitive research. Composites are on DOD's critical technology list.

POLICY ISSUES: Tighter CAFE standards will encourage the use of composites in automobiles. DOD R&D ($170 in FY91) and procurement; Export control; Cost of capital.

CRITICAL TECHNOLOGY: **Electronic and Structural Ceramics and related processing technologies.**

DESCRIPTION: Ceramics -- non metallic and non-organic solids -- used for their electronic or structural properties.

WHY IS IT A CRITICAL TECHNOLOGY? Ceramics' desirable properties such as strength, hardness, temperature resistance, light weight and favorable electrical properties make them "enabling" technologies that make possible other technologies, such as turbochargers and engines, and semiconductor packaging materials. Automotive electronics must survive very stressful environments (high temperature and vibration), and thus packaging is critical.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

		Lag	Par	Lead
Electronic Ceramics = E	1990	E,S		
Structural Ceramics = S	2000	E S		

The United States lags behind Japan in both areas of ceramics

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Underinvestment in industrial research in the United States. Uncertainty about market demand. Weaknesses in U.S. semiconductor industry demand for electronic materials. Foreign targeting.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: R&D in chemistry and ceramics industries. Depends on advanced analytical instruments. DOD and DOE research support has been important.

POLICY ISSUES: Export control; R&D funding; Federal procurement; technology transfer from DOD/DOE labs; Cost of Capital.

CRITICAL TECHNOLOGY: **Steel, Magnesium, and Aluminum Materials and Processing**

DESCRIPTION: High strength steels, coated steels, alluminum alloys, magnesium alloys, metal matrix composites; net shape forming, precision casting, aluminum forming.

WHY IS IT A CRITICAL TECHNOLOGY?

Basic materials and processing techniques with many applications in automobile bodies, structures, and powertrains. Better materials and processing can reduce weight, processing and manufacturing time, and/or reduce waste.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

		Lag	Par	Lead
S=Steel	1990		S	M
M=Magnesium	2000			

The U.S. is better in applications of steel for the automobile industry than it is in steel technology in general.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:

Weak competitive status of U.S. metals and metals processing industries.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:

Material processing technologies.

POLICY ISSUES: Support for materials and processing generic R&D.

CRITICAL TECHNOLOGY: **Opto-electronics and related materials**

DESCRIPTION: Fiber optics, optical switches, optical communication, materials whose optical properties change in a non-linear manner (such as from one stable phase to another) in response to stimuli.

WHY IS IT A CRITICAL TECHNOLOGY? Optoelectronic devices have many applications in automobile information systems.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

		Lag	Par	Lead
R=Research	1990		P	R
P=Products				
	2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Underinvestment by industry in R&D projects with long-term payoffs. Japan is actively pursuing optoelectronic developments.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Solid state physics, optics, microelectronics. "Photonics" is on DOD's critical technologies list.

POLICY ISSUES: Research funding (such as NSF's Lightwave Technology Program). DOD photonics funding is $100 million for FY 91.

CRITICAL TECHNOLOGY: **Intelligent Vehicle/Highway Systems**

DESCRIPTION: Infrastructure for automobile navigation, communications, and traffic management Systems. Consists of onboard systems and infrastructure necessary to monitor and communicate with vehicles to provide information to drivers on traffic and optimum routes, and eventually, to take over some driving functions.

WHY IS IT A CRITICAL TECHNOLOGY? Automobile navigation, communications, and traffic management systems can improve safety, reduce driving time, reduce fuel consumption, and make driving easier.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

J=Japan
E=Europe

	Lag	Par	Lead
1990	J,E		
2000			

Both Europe and Japan are investing more in traffic management systems.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Requires investment in public infrastructure. Japan leads in mass market electronics equipment.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on electronics, computers, systems analysis, and communication technologies. Depends on public infrastructure.

POLICY ISSUES: Department of Transportation's Intelligent Vehicle/Highway System research program.

CRITICAL TECHNOLOGY: **Design of Manufacturing**

DESCRIPTION: Design of the material and information flows in assembly and machining processes.

WHY IS IT A CRITICAL TECHNOLOGY?
A large proportion of workers in assembly plants are not involved in the actual assembly but are managing the flow of materials. Better process design can reduce wasted time and materials, requires fewer people and less inventory, and reduces total manufacturing costs.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

	Lag	Par	Lead
1990	J		E
2000	J	E	

Average U.S. plants lag behind average U.S. plants. Best U.S. plants are comparable to world's best.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
Relatively low priority on manufacturing skills in academia and industry.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Methods for continually improving production processes; quality control; employee involvement; computer integrated manufacturing, CAD/CAE, simulation of process design.

POLICY ISSUES: Engineering education issues. Funding and priorities for DOD's Manufacturing Technology Program; NIST's Manufacturing Technology Centers; National Center for Manufacturing Sciences; NSF's Design, Manufacturing, and Computer Integrated Engineering Program.

CRITICAL TECHNOLOGY: **Integration of Design, Manufacturing and R&D functions**

DESCRIPTION: Methods of integrating design, manufacturing and R&D to make develop products that are easier to manufacture.

WHY IS IT A CRITICAL TECHNOLOGY? Better integration of these functions can lead to products that can be manufactured more quickly and efficiently, and can reduce capital and operating costs of producing a product. Better integration can also help reduce the time from concept to market by increasing the overlap between the advanced engineering, product engineering and process engineering stages of a project, and by reducing the need for rework.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

J=JAPAN

E=EUROPE

	Lag	Par	Lead
1990	J	E	
2000	J	E	

Source: Womack, James P., Daniel T. Jones, and Daniel Roos, The Machine That Changed the World, New York, Rawson Associates, 1991, p. 97.

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Institutional barriers within U.S. companies. Traditionally low involvement of manufacturing engineers in product design. Lack of engineers with training in both product and process engineering.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Computer aided design and engineering, computer modeling, communication, and expert systems can aid the integration process. Taguchi methods.

POLICY ISSUES: Training of manufacturing engineering. Need for engineering disciplines to emphasize both product and process engineering. Funding and priorities for DOD's Manufacturing Technology Program; NIST's Manufacturing Technology Centers; National Center for Manufacturing Sciences; NSF's Design, Manufacturing, and Computer Integrated Engineering Program.

CRITICAL TECHNOLOGY: **Flexible, Computer Integrated Manufacturing.**

DESCRIPTION: Computerized numerically controlled machine tools, automated materials handling, automated tool changing, and other robotics managed under centralized computer control.

WHY IS IT A CRITICAL TECHNOLOGY? Can provide high-speed, high-quality machining in a way that is flexible enough to produce several products on the same line. Helpful in integrating design and manufacturing.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

J=JAPAN

E=EUROPE

	Lag	Par	Lead
1990		J,E	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: High cost of capital. Higher investment in other countries.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Standards are key issue.

POLICY ISSUES: Funding and priorities for DOD's Manufacturing Technology Program; NIST's Manufacturing Technology Centers; National Center for Manufacturing Sciences; NSF's Design, Manufacturing, and Computer Integrated Engineering Program.

CRITICAL TECHNOLOGY: **Adaptive Process Control**

DESCRIPTION: Methods and technologies to collect, interpret and communicate information on manufacturing processes and to use this information to control operations.

WHY IS IT A CRITICAL TECHNOLOGY? Can greatly improve quality and productivity, and lower wastes and production costs. By reducing waste, it can also reduce the capital costs for processing the waste streams.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

		Lag	Par	Lead
J=JAPAN	1990		J,E	
E=EUROPE	2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: High cost of capital makes process improvements more difficult. Future weaknesses in electronics sector could weaken U.S. in process control technology.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Depends on sensors, computers and software. Interrelates with process design and simulation technologies. Also depends on mathematical modeling, signal processing and control theory.

POLICY ISSUES: Cost of capita [illegible] R&D support for related technologies.

CRITICAL TECHNOLOGY: **High performance computers and software for process and product modeling**

DESCRIPTION: High speed computers and specialized scientific and engineering software for the needs of the automotive industry. Also includes graphic work stations that interface with the computers.

WHY IS IT A CRITICAL TECHNOLOGY? They are powerful tools in analyzing many problems of importance to the automotive industry (e.g. in combustion, aerodynamics, crash worthiness). They are important tools in the design of automobiles, automotive systems (such as engines) and production processes. They make it possible to design and simulate the performance of many alternative configurations of a design or process, greatly accelerating the design and testing process.

U.S. POSITION RELATIVE TO THE REST OF THE WORLD:

Computers = C
Software = S

	Lag	Par	Lead
1990		C	S
2000		C	S

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: U.S. is strong in software, which is key. In the long run, U.S. supercomputer industry may be financially weaker than its Japanese competitors. (See computer industry sectoral profile).

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Applications in auto industry are dependent on software. DOD funding has been important to computer industry in general. Parallel computer architecture, and simulation and modeling are DOD critical technologies. Related to artificial intelligence. Computational fluid dynamics, which has applications to modelling aerodyamics and combustion, is also a DOD critical technology.

POLICY ISSUES: Supercomputer network bill. (See computer industry sectoral profile)

CRITICAL TECHNOLOGY: **Artificial Intelligence and Neural Networks**

DESCRIPTION: Electronic and electromechanical systems incorporating knowledge-based control systems. Includes expert systems, intelligent machines and process controls.
Neural networks are computers designed to mimic the brain's network of neurons that are programmed to "learn" from data to recognize patterns.

WHY IS IT A CRITICAL TECHNOLOGY? Expert systems can aid both design and operations by providing encoded expert advice. Can improve analysis and interpretation of data. Can also be used to help transfer expert knowledge from one part of the corporation to another.

Neural networks excel in recognizing patterns, which is a weakness of traditional computers and software. Neural networks thus extend the use of computers into new areas, such as identifying optimum production conditions and deviations from acceptable conditions.

U.S. POSITION RELATIVE TO RoW:

		Lag	Par	Lead
J=Japan	1990		J	E
E=Europe				
	2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
Shortage of artificial intelligence researchers and engineers.
Dedicated efforts in Europe and Japan.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Related to databases, computer hardware and software, biological and cognitive sciences. DOD funding and applications are important. "Machine intelligence and robotics" is on DOD's critical technologies list.

POLICY ISSUES: R&D funding; science and technology manpower issues. DOD funding of machine intelligence and robotics is $120 million (FY91).

CRITICAL TECHNOLOGY: **Joining and Fastening Techniques**

DESCRIPTION: Adhesive bonding, laser welding, and other advanced joining and fastening techniques.

WHY IS IT A CRITICAL TECHNOLOGY?
Much of the effort in assembling an automobile is in joining parts. Improved methods of joining parts can simplify the production process, reducing capital equipment and assembly time.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		J,E	
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY:
Lack of emphasis on manufacturing and manufacturing R&D; high cost of capital.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES:
Relates to developments in lasers and in adhesives.

POLICY ISSUES: Support for manufacturing R&D; cost of capital.

CRITICAL TECHNOLOGY: **Environmental Technologies**

DESCRIPTION: Technologies for reduced emissions and waste from manufacturing plants; recycling and waste management technologies, especially for plastics and composites.

WHY IS IT A CRITICAL TECHNOLOGY? Tighter controls on emissions and wastes from manufacturing and processing plants, will require new technologies to meet standards at low costs. increased use of plastics and composites materials in automobiles will require ways of recycling those materials.

U.S. POSITION RELATIVE TO RoW:

	Lag	Par	Lead
1990		E	J
2000			

THREATS TO U.S. RETAINING/GAINING PROMINENCE IN TECHNOLOGY: Regulations that do not permit innovative ways of meeting the same goals. Short term industry view that resists change. Confrontational relations between industry, government, and public interest groups that do not allow optimum solutions to problems. High costs of capital. Shortage of skilled researchers and engineers.

TECHNOLOGICAL INTERDEPENDENCIES - RELATED TECHNICAL ISSUES: Improved process design and control, catalysts, biotechnology, membranes, and synthesis all contribute to improved environmental technologies.

POLICY ISSUES: Effect of regulatory environment on innovation. Cost of capital. Federal R&D funding.

III. THREATS TO U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

Lack of Attention to Manufacturing Engineering

There has been a historical lack of attention to manufacturing engineering in the United States, which has contributed to a relative U.S. weakness in this area. U.S. government R&D funding, and consequently university research and teaching, put low priority on manufacturing. Within companies, manufacturing has not been seen as a way to the top. German and Japan put higher emphasis on industrial engineering.

Weaknesses in Getting Technology to the Market

U.S. automobile companies are improving their ability to get products to the market, but still lag behind Japanese automakers. Nevertheless, there are still substantial internal barriers to transferring technologies. GM, for example, noted that their accounting system cannot make allowance for the fact that a lighter but more expensive component in one part of a car might reduce the cost for the whole car.(28) Similarly, U.S. automakers have lagged behind Japanese automakers in integrating design of products with the design of the production process.

To get a new automobile quickly from concept to commercialization with high quality, it must usually use proven, "off the shelf" technologies. A weakness of the U.S. automotive industry relative to Japan is in getting advanced technologies "on the shelf" -- sufficiently developed and proven so that they can be used in a new production car.(29)

Barriers to Long Term Investments

U.S. industry is commonly perceived to invest less in long-term investments than do Japanese and German companies. Among the hypothesized reasons for this are higher cost of capital in the United States and greater pressure by shareholders for short-term profits.

Lack of Constructive Relations with DOT and EPA

The motor vehicle industry is strongly affected by auto and plant emission regulations, auto safety regulations, regulations governing disposal of wastes, and Corporate Average Fuel Economy (CAFE) regulations. These regulations have a major effect on technology development in the industry. For example, tightening CAFE requirements will likely encourage the use of much lighter materials in automobiles. The way that the CAFE standards categorize cars as domestic or imports based on the amount of domestic content influence to what extent to

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28 Dr. Robert Frosch, General Motors, personal interview, June 1990.

29 Tom Moore, General Manager, Liberty Project, Chrysler, personal interview, June, 1990. Robert Frosch of GM noted that the U.S. is weak in what corresponds to the Department of Defense budget category 6.3 -- advanced exploratory development. Personal interview, June 1990.

which companies use overseas suppliers. Similarly, stricter fuel emissions requirements could lead to changes in fuel type or engine designs.

The regulatory environment for the automobile industry largely took shape in the 1970s, when the U.S. auto industry was seen to be invulnerable and competitiveness was not an issue. The regulations were also developed and interpreted in arenas, such as Congress and the courts, where the relations between industry and government were more adversarial rather than cooperative. As one study noted: "... the legislative record suggests that some members of Congress and their staff operated on the assumption that, if industry does not oppose it, it must be too lenient."(30)

The effect of regulations has not been totally negative on the competitiveness of the automobile industry. Foreign automobile manufacturers must meet essentially the same standards. The CAFE standards made the automobile industry better prepared for the shift in consumer preferences towards more fuel-efficient cars in the late 1970s. There is little doubt, however, that with more cooperation between industry and government many of the regulations could have been design to achieve the same public purpose while having less impact on the competitiveness of the industry.

Lingering Antitrust Distrust

The automobile industry has begun to cooperate in conducting pre-competitive research on automotive technology. For example, Ford, Chrysler, and GM are funding the Automotive Advanced Composites Consortium. Cooperative research, however, is still inhibited by uncertainty in the antitrust environment. Although enforcement of antitrust laws is more permissive than before, little has formally changed and the uncertainty in the interpretation of antitrust law still inhibits cooperative R&D. Cooperative research to improve safety and emissions technologies were forbidden for many years under a consent decree design to prevent collusion, and, although now permitted, there is still reluctance to do cooperative research in these areas.

Weaknesses in Related Industries

Weakness in industries that are suppliers to the automobile industry can be expected to lead to weaknesses in technology for the automobile industry. For example, many of the most advanced machine tools are now built in Japan. When the latest models fo machine tools become available to U.S. manufacturers, they are like to have been available to German or Japanese automakers for some time. Electronic components are expected to make up an increasingly large percentage of the value of cars, from roughly 10% of the value in 1987 to 20% by 1995.(31) Given the relative weakness of U.S. mass market electronics relative to the

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30 National Research Council/National Academy of Engineering, The Competitive Status of the U.S. Auto Industry: A Study of the Influences of Technology in Determining International Industrial Competitive Advantage, Washington, National Academy Press, 1982, p. 82.

31 Cole, David E., Michael S. Flynn, and David J. Andrea, "Transition in the Automotive Industry," Automotive Engineering, February 1989, p. 149-154.

Japanese, it might be expected that unless the U.S. electronic sector can maintain its competitiveness that increasing amount of automobile components will come from overseas. If U.S. automakers do not have access to the latest generation of electronics, the level of technology in U.S. cars may lag behind Japanese cars. New, more cooperative relationships with suppliers, including more cooperative technology development activities are key to strengthening the suppliers.

IV. FACTORS SUPPORTING U.S. LEADERSHIP IN CRITICAL TECHNOLOGIES

Strong Companies Operating Globally

The major U.S. automobile companies, especially GM and Ford, are strong, somewhat vertically integrated, multinational companies. They can attract technology and skills from around the world, and take advantage of the benefits of each area of the world. Operating globally gives them an opportunity to learn from the rest of the world.

Strong Technical Capabilities

General Motors and Ford, and to a lesser extent Chrysler have strong internal R&D programs and technical resources. Many of the suppliers to the industry are also technically strong companies.

Large Domestic Market

The U.S. automobile industry benefits from having the largest domestic market in the world, which should give them an advantage in developing products for that market.

Foreign Investment

Foreign automaker setting up plants in the United States is improving the competitiveness of the U.S.-based automobile makers, but pose a competitive threat to the U.S.-owned automakers. These New American Manufacturers (NAMs) have invested in new plants and have shown that U.S. based production can produce high quality automobiles that both reduce the number of imports from Japan and can be exported themselves.

Learning from Foreign Companies

U.S. automobile companies have had the opportunity to learn from joint ventures with Japanese automobile companies to improve their quality, production process, and processes of getting new products to the market. This learning has facilitated enormous improvements in products and in quality.

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

This research paper was prepared by Council Senior Associate David W. Cheney. John McTague and Norm Gjostein of Ford Motor Company provided invaluable assistance.

The Council would like to thank Pfizer Inc. and NMTBA/The Association for Manufacturing Technology for their assistance in publishing the profiles.

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***Dr. Spencer served on the Committee in his role as Vice President, Science and Technology, Xerox Corporation, prior to his appointment to Sematech.**

ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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A COMPETITIVE PROFILE OF THE TELECOMMUNICATIONS INDUSTRY

Research Paper for

GAINING NEW GROUND: TECHNOLOGY PRIORITIES FOR AMERICA'S FUTURE

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As part of the research for *Gaining New Ground*, the Council on Competitiveness analyzed the competitive standing and technology priorities of nine industrial sectors: (1) Aerospace; (2) Chemical and Allied Products; (3) Computers and Software; (4) Construction; (5) Drugs and Pharmaceuticals; (6) Electronic Components and Equipment; (7) Machine Tools; (8) Motor Vehicles; and (9) Telecommunications. The views expressed in these profiles do not represent the official position of the Executive Committee of the Council. Their consensus findings and recommendations are contained in *Gaining New Ground: Technology Priorities for America's Future.*

Copies of these sectoral profiles may be obtained from the Council on Competitiveness, 900 17th Street, N.W., Suite 1050, Washington, DC, 20006, (202) 785-3990. The prices are $10 for each profile plus $1 postage and handling and $20 for *Gaining New Ground* plus $2.50 postage and handling.

Telecommunications

SECTORAL PROFILE

EXECUTIVE SUMMARY

Industry Characteristics

Changes continue to take place in the telecommunications industry as a result of advances in electronics, computer and communications technology. These changes are reflected in company structure, competitors, product and service offerings. Changes in telecommunications policy, industry structure, technology and applications all interact.

Telecommunications is a key to improving efficiency in the manufacturing, services, natural resources and finance sectors of an economy.

The telecommunications business consists of both wired and wireless communications carrier services, value added services, and associated equipment and software.

The principal technological drivers of change in telecommunications include: advances in network technology that distributes control intelligence throughout the telecommunications network, increasing pressure for easily accessible data communications at speeds above those now available through voice-grade analog service, development of new types of user equipment, business needs for flexible, high capacity services, and expanding market for mobile services, and changes in local service technology. In addition, future business possibilities for software-based information services and demand for lower operating costs to counter balance increasing labor expense are indirect driving factors.

Critical Technologies

With few exceptions, technical issues in the telecommunications sector relate primarily to development, manufacture and deployment of equipment using known technology.

The critical technologies are:

- Cost effective **User Terminals** employing new technology to extend the range of options available to telecommunications customers.
- **Digital Infrastructure** to support the conversion of telecommunications technology from analog to digital transmission.
- **Software** to provide the embedded instructions that govern the operation of the computer-controlled telecommunications network.

- **Portable Equipment and Systems** to provide a full range of telecommunications services without the need for wired connection to the telecommunications network.

- **Optical Fiber Technology for Local Service** capable of transmitting the full range of video, digital and voice services over distances of several thousand yards.

- **Broadband Switching** technology for central offices compatible with the wideband signals transmitted over fiber optic interoffice and local service systems.

- **Database Architecture** technology for organizing stored data within the telecommunications system, both system- and user-generated, for efficient access.

Critical Issues

Regulation of the telecommunications industry is complex, with many bodies having overlapping jurisdictions. Many telecommunications policy issues relate to regulation of the industry by the courts, federal, state and local regulatory agencies, the FCC, and standards bodies.

Although the U.S. telecommunications infrastructure has historically led the world in many respects, other advanced industrial nations are modernizing their communications systems at a proportionately more rapid rate. A key issue for the United States is how we manage the continuing modernization of our national telecommunications infrastructure to ensure its continued leadership role in increasing the efficiency of our economy as well as serving the consumer public.

I. CHARACTERISTICS OF THE INDUSTRY

Increasing convergence of computer, video and telecommunications technologies has changed many aspects of what once was largely a well-ordered telecommunications utility industry. The rapid and profound changes that have occurred, and are continuing to take place, have been reflected in the re-structuring of major companies in the field, the appearance of entirely new competitors, disappearance of participants, demands by customers for new kinds of business relationships, and development of new products and services. Change has come rapidly. The telecommunications industry began its current transformation with the Carterphone court decision in 1969. That decision to open telephone network connections to non-carrier supplied terminals, together with a 1959 FCC action to liberalize licensing of microwave transmission systems, established the United States policy to break the virtual monopoly of telecommunications service and equipment supply.In addition, supply of equipment for the U.S. industry, which once was strictly domestic, has been opened to worldwide competition.[1] Similar changes have now been instituted in other countries (notably the U.K. and Japan).

Like the network that lies at its heart, changes in telecommunications policy, industry structure, technology and applications all interact. Shifts in one area beget transformations in all the others.

Operating revenues for domestic services in 1989 were \$168B, international services \$3.4B,[2] and shipments of equipment totalled \$18B.[3] The service and equipment production portions of the industry employed approximately 1,000,000 workers.

Effective telecommunications is a major factor in enhancing the efficiency of many sectors of the economy, in manufacturing, services, natural resources and finance. Ubiquity and quality of the telecommunications infrastructure vary from country to country. The ability of the United States to continue leadership in this area is an important factor in its ability to compete.

Structure

For purposes of this analysis, the telecommunications business consists of both wired and wireless communications carrier services, value added services, and associated equipment and software. Not included (except as noted) are the consumer television and radio broadcast industries or consumer broadcast reception products. This paper focuses on the U.S.

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[1] Carr, Edward, "Survey: Telecommunications", The Economist, March 10,1990

[2] U.S. Department of Commerce, U.S. Industrial Outlook 1990, p. 31-1

[3] Bruederle, Stanley, Dataquest, private communication

domestic industry, noting developments abroad only as they affect the U.S. competitive position.

Wireline Carrier Services

The wireline telecommunication business provides public switched and private, local, long distance, and international connections for the transmission of voice, text, data and video information. Voice communications, which account for more than 80% of wireline services, are the slowest growing at 3 to 5% per annum. Transmission of digital data, on the other hand, is rapidly expanding at a rate of 25 to 30% per year. Pressures to allow competitive forces to govern the rapid change from a traditional voice telephone system to one that is efficiently matched to new market service needs were one factor behind the U.S. government move to breakup AT&T.

Nearly 94% of U.S. homes have telephone service,[4] and as Figure 1 shows, the United States has one of the highest numbers of residential telephone lines and lines per capita in the world. Local public telephone service is almost exclusively a monopoly with local telephone companies required to provide universal access to the telecommunications network.

The challenge facing local switched service providers is not survival, but avoiding becoming staid, slow-growth utilities. For these companies, whose revenue totalled approximately $76B in 1989, the future does not rest with traditional telephony; opportunity lies in upgrading their businesses to encompass the more rapidly expanding computer- and information-based services, cellular services and manufacturing opportunities that they believe underlie the coming information age.

Long distance telephone service, declared by the court judgement that resulted in the breakup of AT&T to be off-limits for RBOC's,[5] has been opened to competition, and five major firms and numerous small companies compete for a $61B market that is growing at the rate of approximately 10% per year.

As a supplement to the public switched telecommunications network (PSTN) provided by wireline companies, many large corporations realize the need to custom tailor private communications networks and equipment to support strategic dispersal of engineering, manufacturing, marketing, sales, service, finance and management activities on a nation-wide and even global scale. Real-time transaction completion is at the heart of modern business practices such as just-in-time manufacturing management, electronic funds transfer, automated teller retail banking, on-line retail inventory management, remote newspaper publishing and electronic mail. **Large companies are now able to design telecommunications networks to match their business activities and to realize substantial savings by leasing, or owning outright, dedicated private telecommunications networks, thus bypassing the PSTN.**

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[4] op cit: U.S. Industrial Outlook-1990, p. 31-1

[5] U.S. vs. Western Electric Co. Inc., et. al.: Notice of Entry of Final Judgement. 47 Fed. Reg. 40392, September 13,1982

In addition to large corporations, new computer telecommunication service companies have also established national and worldwide private networks to provide computer communications and electronic mail services to individual users and smaller companies.

Many medium- and large-size firms have achieved substantial savings on their telecommunications costs by using central exchange services (such as Centrex) with on-site leased or owned private branch exchanges (PBX's) to handle intra-office telephone services. With liberalization of wired telecommunications, competition between traditional telephone equipment providers and new suppliers has increased.

Finally, a new, non-switched residential service, cable, has arisen to meet demand for new consumer entertainment options. Cable, which parallels residential telephone service in many localities, is generally one way, and provides mostly television broadcast entertainment.

All this is a far cry from the single voice telephone system that existed prior to the 1970's, all of whose services were provided by the telephone utility. Table I gives a listing of the major types of companies competing for portions of the wireline telecommunications market.

Wireless Carrier Services

The convergence of computer, video and telecommunications technologies that has provided the impetus for changes in the wired telecommunications has also led to the establishment of many new types of wireless public telecommunications providers, including cellular telephone system operators, paging services, Airfone, satellite communications services, satellite-based position location, direct broadcast entertainment and computer communications network services, some of which offer alternatives to conventional wired telecommunications. At present, the primary advantage of non-wireline services is portability.

The current revenues for non-wireline services is modest, at approximately $3B, however the growth rate is high (nearly 55%/year for cellular radio in some locations, for instance).

Non-wireline services offer capabilities (such as mobility) that supplement wireline services, however they also offer alternatives to wireline service. The U.K. is experimenting with a microwave radio service called PCN (for Personal Communications Network) that would replace subscriber wiring in home and office and Japan has based its future high definition television standard on satellite direct broadcast.

Non-wireline services require radio spectrum, a fixed, non-expandable resource. The United States, as the country currently having the most highly developed radio communications capability, has the most crowded spectrum. The problem is exacerbated by the assignment of a large portion of the UHF radio spectrum to the television broadcast service, which is under-utilizing this resource. Europe, Japan and the rest of the world have far fewer existing radio services, and in many cases central control over many radio spectrum users (such as PTT's and broadcasters) that facilitate more efficient spectrum allocation.

Table II gives a list of types non-wireline competitors.

Value-Added Services

Value-added services, the newest portion of the telecommunications industry, provide users with information services using existing carrier networks. The largest portion of the value-added business consists of data processing services and on-line data bases that provide the user with computational and archival resources on-line at his location. Some other value-added services include telex, low-cost packet transmission of data, gateways for public information services, electronic mail, alarm and monitoring capability, alternative operator services and banking services. Still others provide communication services custom tailored to business needs (such as turn-key private networks), or technical services to assist new private network users in engineering their communication capabilities to meet company needs.

In 1989, value-added service revenues totalled approximately $5.5B for public data networks, on-line data bases, electronic data interchange services and special services such as electronic mail, credit validation and alarm services. Associated on-line data processing services totalled $30B.[6]

Value-added services are seen by many as a rapidly growing new business to supplement some of the more mature portions of the wireline network service business. A listing of representative value-added service providers is given in Table III.

Telecommunications Equipment

The telecommunications equipment business has undergone changes as great as those experienced during the past 22 years in the service businesses. Telecommunications technology advances have radically changed the nature of equipment, as mechanical switching, copper wire and rotary-dial telephones have been replaced by digital electronic exchanges, fiber optics, and new subscriber terminals. Performance has improved and operating costs have dropped significantly for all equipment types.

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[6] op cit: U.S. Industrial Outlook, p. 31-4

The U.S. telecommunications terminal and network equipment market, which once was supplied by AT&T and a few other U.S.-based companies has now been opened to participation by competitors based anywhere. In addition, U.S.-based telecommunications manufacturers have moved major manufacturing activities abroad in order to remain competitive and to gain access to foreign telecommunications equipment markets. Figure 2 shows the growth of telephone equipment sales, both for the world and the United States during recent years.

The production base for customer premises equipment (CPE) has also undergone major changes during the past two decades. Business office telephone switching, which once was handled mostly within the local central exchange through a service called Centrex, has moved into the customer premises as the price and availability of private branch exchange (PBX) switches have improved. Numerous firms have entered the PBX business as the market has opened up to competitors.

In addition, much intra-premises data communications is carried out over broadband, short-range local-area networks (LAN's), which have provided a major expansion opportunity for computer and office equipment manufacturers into on-site communications equipment.

New user terminal equipment to provide expanded services, such as telephone answering machines, voice-mail and FAX machines, has become commonplace as user demand for new capabilities has risen. Telecommunications products now form a rapidly growing part of the consumer electronics business. Residential telephone sets are no longer made in the United States, even by U.S.-based suppliers, although business key-sets are still produced here.

1989 shipments of telecommunications equipment totalled approximately $18B, of which wireline network equipment (including central offices) totalled $12.7B and customer premises equipment (including PBX's, LAN's and terminals) was $3.7B. Non-wireline equipment sales amounted to approximately $2B.

As the U.S. wireline telecommunications sector has been restructured, new opportunities have appeared for foreign suppliers of all types of telecommunications equipment, user terminals, PBX's and network equipment. Figure 3 shows U.S. trade and trade balance for telephone equipment, and Figure 4 indicates the breakout of these data by type of equipment. Note that the largest negative balance occurs in the "Telephone Instruments" category -- user terminals -- which play to the strength of foreign consumer electronic suppliers. The portions of the telecommunications equipment industry most susceptible to consumer electronics foreign competition are those (such as user terminals and local line electronics) that must be provided to each individual subscriber. While telephone instruments exhibit the most negative trade balance, however, competition from foreign-based firms in the switch business has also resulted in a negative balance of payments that is worsening.

Table IV indicates the nature and range of companies engaged in competing for portions of the telecommunications equipment business, and Figure 5 shows the relative size of the components of the world telecommunications equipment business.

Role of Technology

The rapid development of digital computer technology and its deployment in telecommunications applications is the driving force behind the changes in the telecommunications sector. These changes have manifested themselves in three ways: alteration of network technology, expansion in communications equipment available to users, and change in the services demanded by consumers to support new data communications requirements. A number of technological driving forces are propelling changes not underway in the telecommunications system. These include: distribution of intelligence throughout the network, increased pressure for data services, new types of user terminal equipment, needs of business users, pressure for mobile services, changes in local connection technology, software-based services, and cost reduction.

Distribution of Intelligence throughout the Network

The traditional telephone network, where network control resided in central office switches, is giving way to a system where control intelligence is shared between central office controllers, PBX's, and user terminal equipment.[7] The user now has more options for service trade-offs between customer premises equipment (such as PBX's) and carrier-provided services than ever before. There is no longer a point of central control for many aspects of the national telecommunications network. Although subject to overall central management, many of today's computer networks are designed so that messages wend their way through the various nodes and trunks making up the system without achieving direct connection between message originator and receiver.

The development and deployment of common-channel signalling technology, which uses a channel separate from the call data transmission channel to set up and control the call, gives the large business user still more flexibility in making rapid changes in packet switching services, channel capacity and call destination.

Distribution of intelligence throughout the telecommunications network opens up new possibilities for trade-off between control residing in terminal equipment and in the central office. At the same time, networks having distributed control can easily become instable, and are vulnerable to errors that propagate through the system, as in the switching software problem that propagated through the AT&T network on January 15,1990. In addition, maintenance of network security and integrity has become a new, complex challenge.

Increased Pressure for Data Services

The use of computers, first in centralized computer centers, and increasingly, distributed widely as personal computers and work stations in offices and residences, creates demand throughout the network for data interchange between machines. As machine performance has improved, requirements for increased data rates and error-free transmission have increased. Rate of data transmission possible over voice-grade lines has increased from 120 bits/second to 9600 bits/second. Currently, most data moves at low rates (typically 1200 bits/second).

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[7] Huber, Peter The Geodesic Network

Early mainframe-to-mainframe data communication was handled over dedicated lines, which were installed by carriers on an exception basis. **As computers become more pervasive, treatment of digital data communication as an exception can no longer be tolerated -- dial up service through the public network and routine provision of broadband service is necessary.** Personal computer applications that now can be satisfied with voice-grade telephone service with a modem, will soon require direct digital communication connections for higher transmission capacity and lower error rates as higher performance work stations become common, and as routine data file size increases to incorporate images. Users who now are content to use 1200 and 4800 bit/second modem-supported data transmission on standard voice-grade lines will demand dial-up direct digital transmission rates above 20,000 bit/second as work station data bases, high quality graphics and video images become an increasing part of personal computer data files.

A standard access arrangement for direct digital communication over the wireline network has been developed (called ISDN, for Integrated Services Digital Network) that will carry voice, data and video interchangeably over a standard 64,000 bit/second channel. ISDN is in early stages of deployment in most countries.

In addition to PSTN and private data networks, the United States has in place a number of specialized networks for interchange of computer data. The earliest of these, a low speed network called ARPANET, provided opportunities for development of data communications technology now used in numerous specialized, interconnected data operating as Internet.

Pressure is mounting for a high performance computer data network, termed the National High Speed Data Network, that would efficiently support data transmission needs of supercomputer as well as individual users.[8] Bills to develop and deploy such a network have been introduced into Congress, and have wide support from the computer science and telecommunications communities.

New User Terminal Equipment

The range of equipment widely available to subscribers has expanded during the past twenty years. To the twelve-button telephone have been added automatic dialers, answering machines, modems, facsimile transmission sets, speaker phones, and cordless telephones. Telecommunications user equipment has become a rapidly growing part of the consumer electronics business. **The addition of video capability to the conventional voice service could make possible an entirely new range of integrated voice/video terminals and teleconferencing products.**

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[8] Palca, Joseph, "Getting Together Bit by Bit", Science, vol. 248, April 13,1990, p. 160.

Business Communications Requirements

As businesses are increasingly building strategies around telecommunications, their communications costs are rising. The average corporation spends over 1 percent of its operating budget on moving and manipulating information.[9] Companies are increasingly turning to privately-owned or leased networks to cut telecommunications costs. At present, private networks are primarily the domain of large companies who can afford the engineering and operating staffs required, however deployment of ISDN primary service (1.544 megabits/second channel) may provide medium- and small-sized firms with public network services similar to bypass capabilities.

Design and control of these networks can be a complex undertaking, which will become more challenging when ISDN digital technology is deployed. Future network services will not only require the user to provide information about the origin and destination points to be connected, but also channel capacity. Network engineering and control equipment for use in private networks will be needed to realize the best match of service to business needs.

Expanding Market for Mobile Services

The rapid growth of cellular telephone service has proven that a large market demand exists for mobile and portable telecommunications services. Cellular telephone service now covers 85% of the population of the United States, and services approximately 2.6 million users.[10] Paging services have become a fact of life for many workers in jobs that require them to be on-call, even on a nation-wide basis. Businesses have realized that increased efficiency of personnel in the field results from appropriate mobile communications.

As more people become used to cellular and cordless telephone services, and as prices for equipment and service fall, mobile and portable telephones are being used to supplement residential service. "Eventually the price and convenience of using a mobile telephone might even rival that of a conventional, fixed telephone. If so, mobile telephony could threaten to steal business away from traditional carriers."[11]

The major impediment to increased portable services in the United States is availability of radio spectrum. Growth of new radio services is already significantly impeded by shortage of available usable frequencies well up into the microwave region of the spectrum.

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[9] op cit: U.S. Industrial Outlook 1990, p. 31-2

[10] Cellular data footnote

[11] op cit: The Economist, March 10,1990, p. 12.

Major expansion of radio-based portable services requires re-allocation of frequencies away from broadcast television (most of whose channels are unused) and fixed microwave (much of which is being replaced by fiber technology) to land mobile uses.

Changes in Local Service Technology

Typically, the connection between the subscriber and the central exchange is the last part of the telecommunications infrastructure to be up-graded to new technology. It represents the largest fixed investment for local exchange carriers, and requires the longest time and greatest disruption to change. **The local connection, however is now the greatest bottleneck in offering advanced services to residential users and small business users.** New technology developed for subscriber loop applications could make a significant difference in potential service offerings.

Optical fiber communications technology (both the fiber itself and its electrooptical interfaces) is replacing older microwave and electrical cable broadband technology. Numerous large telecommunications data users (universities and companies) have already installed broadband fiber systems to interconnect campus facilities.

Existing residential fiber technology exists that has enough capacity to handle not only residential telephone and data service (using ISDN) but also video, including broadcast and cable TV, as well as future interactive video services. The cost of replacing the current wired local loop installed base with fiber, however, is staggering, and, according to the RBOC's, only justifiable if television and other expanded services can be offered.[12] The possibility of transmitting entertainment television over the local exchange carrier network creates a major competitive problem for cable TV service providers.

Wireless telecommunications is another alternative to the existing local loop. In this case, local loop wiring would be replaced by short-range, neighborhood microwave transceivers that operate as a "micro-cellular system". A British version of this system, called PCN (Personal Communications Network) is undergoing trial deployment in the U.K.. Wireless alternatives to the local loop are much more economical to install, and give the subscriber freedom from wire interconnection, however the wireless system does not provide the bandwidth needed for expanded services and spectrum has not yet been allocated in the United States for such a service.[13]

Software-based Services

Many services now available through telecommunications networks are the product of software. Information services, such as videotex, audiotex, time and weather, and a host of other new consumer dial-up services, are provided by independent companies through "gateways" provided by local exchange carriers. Under current rules[14] RBOC's are prohibited from offering such information services.

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[12] RBOC filings with NTIA

[13] Reference to documents filed by Motorola in response to NTIA Notice of Inquiry on spectrum allocation

The other set of software-based services is imbedded in central office and network switches, and is known to consumers as 800 inward calling service, 911 emergency service, billing, call waiting, call forwarding, conference calling, call identification, and so on. To telecommunications companies, these are the controls that route calls through the network. Since modern, electronic switches are computer-controlled, changes in services usually require only little more than an up-date of the switch's operating programs.

As the base of switch suppliers to U.S. exchange and long distance carriers has diversified following the AT&T breakup, however, problems with incompatibility of the software controlling switches made by various manufacturers have become a problem to exchange carriers. Standards exist for signal communication between switches, but not for interactions of their operating systems. Since software up-dates for a given switch are generally available only from the manufacturer of the switch, operating companies are forced to rely on that vendor for support in implementing and maintaining software for the life of the switch (often 30-40 years).

Cost of Telecommunications Service

The impetus behind deployment of new technology within the telecommunications system has been, and remains, cost reduction to offset rising labor costs. Broadband fiber long distance trunks have much greater capacity than microwave or coaxial cable technology, and the cost per channel is significantly lower. Electronic exchanges are less expensive to produce and operate than are older mechanical switches and Touch-Tone is less expensive than rotary-dial.

How these cost reductions are reflected into the strategy of operating companies is a function of the federal, state and local regulatory policies that each must satisfy. Allowable rates of depreciation and investment vary from jurisdiction to jurisdiction, as do allowable costs that can be reflected in the rate base. **Deployment of new technology and services throughout the national infrastructure is a function both of operating savings to be realized and the regulatory environment.**

Market Pull vs Technology Push

The future of telecommunications will be a mixture of technology development and deployment and market demand. The network infrastructure, within which changes occur slowly as the depreciated equipment base is gradually replaced by newer equipment embodying up-dated technology, is the slowest portion of the system to respond. Capability must be planned well in advance of customer need.

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[14] op cit: U.S. vs. Western Electric

Market need for many of the data services and broadband capabilities now being installed in the wireline system are most evident for large company users. For residential users, the need for new services is much less apparent. As the Consumer Federation of America puts it, "The fact is that the U.S. telecommunications infrastructure is simply in great shape today."[15] Future services based on integrated voice/video capability, telecommuting, home shopping and on-line data are as yet unproven in the market place, although technologically straight-forward.

Like many other industries, the telecommunications industry has had past problems with developing technical services, such as Picture-Phone, that proved to have had little market acceptance. The highly subsidized French Minitel videotex terminal program may be a similar instance where the technology is ahead of consumer demand. The average house uses the Minitel terminal only two minutes/day.[16] **Ultimately, a major factor in the deployment of advanced subscriber loop technology will be consumer demand for as yet undefined new services.**

United States Competitive Position

The U.S. telecommunications infrastructure remains competitive for existing services, but is running the risk of lagging behind several other industrialized nations in delivering advanced services to users.

The United States' public network telecommunications infrastructure has historically led those of other nations in its extent, per capita coverage, quality and technical excellence. A recent comparative study, prepared for submission to the Nation Telecommunications Administration, however, concludes

> any presumption about continued U.S. superiority in the public telecommunications arena deserves careful re-examination.[17]

and,

> Rapid progress in network modernization is occurring in many nations. Most notably, France and the United Kingdom have dramatically upgraded their

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[15] op cit Telecommunications Infrastructure in Perspective, p. 5

[16] op cit: The Economist, p. 28

[17] Davidson, William H., A Comparative Assessment of National Public Telecommunications Infrastructures, Management Education Services Associates, Redondo Beach, CA, April 9,1990

> public networks in terms of switching and transmission technology, and in the scope and sophistication of services. Similar patterns are evident in Japan and other nations.[18]

Based on a number of indices of wireline telecommunications service, the U.S. system compares very well to that of other countries.[19] Telephone lines reach a higher percentage of our population than in other lands, we make more calls per person than any other nation, fewer U.S. calls fail to go through than any other country, and we have a higher percentage of computer-controlled central switches than anywhere else. We have the highest penetration of cable television service. **From a consumer standpoint, given the existing service offering, the U.S. system provides the world's best, most used service.**

Residential consumer satisfaction, however overlooks the role the telecommunications must play in sustaining and improving the competitiveness of the U.S. economy. What these indices do not show is the future potential of expanded service, particularly to commercial users, and its impact on economic growth and productivity.[20]

The general role of telecommunications in changing our culture, the way our democratic processes work, and life of individuals is clear.[21] Telecommunications has also made major changes in the effectiveness of business operations. The impact of the advance of telecommunications and computer capabilities has been clear in finance, natural resources, services and manufacturing sectors of the economy as shown in Table V -- the list of the top 50 communications users in the United States.

This impact is related to the growth of the "Information Age". Ninety percent of the jobs created in the United States during the last decade were related to the creation, processing and manipulation of information.[22] Real-time transmission of information is an important facet of preserving its value. Companies such as L.L. Bean, Home Shopping Network and a number of agricultural cooperatives have switched their business operations from the mail to a telecommunications base as service and equipment capabilities have improved.

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[18] ibid

[19] op cit The Telecommunications Infrastructure in Perspective, pp.8 -12

[20] Keyworth, George, Telecommunications publications based on work done at the Hudson Institute

[21] U.S. Congress, Office of Technology Assessment, Critical Connections: Communications for the Future, OTA-CIT-407 (Washington D.C. U.S. Government Printing Office, January 1990) pp 45-210.

[22] U.S. Bureau of Labor Statistics, Employment Projections for 1995, Bulletin 2197, (March 1984)

Several studies that correlate development of national telecommunications infrastructure, economic development and productivity improvement are reported in documents filed before the National Telecommunication Information Administration.[23]

Telecommunications service and equipment advances have increased the efficiency and productivity with which many businesses operate, and hence contribute in a direct way to the competitiveness of U.S. industry. The change does not come automatically, however. The need to match telecommunications services to specific company strategies makes effective custom communications engineering an important function in modern, large corporations.[24]

The general benefit of improving the telecommunications infrastructure is not, however, universally agreed upon. The Consumer Federation of America in its report, Telecommunications Infrastructure in Perspective,[25] makes the point that accelerated upgrading of the U.S. telecommunications infrastructure will not produce real benefits from the individual user's perspective, and that other national priorities, such as health care and education, are more important national investments.

Several other major industrialized countries have realized the importance of a modern telecommunications infrastructure in carrying forward plans for national economic development. France was the first to mount an aggressive program to modernize its system, followed by the U.K., Japan, Hong Kong, Singapore, and West Germany. Japan has aggressively installed broadband digital service to support its concept of the coming "Information Age". A number of these countries started with very poor installations (notably France) and have made significant progress. These and other countries are also upgrading their wireless capabilities with conventional cellular telephone, PCN, improved cordless telephone, and a new generation of digital cellular.

The U.K. and Japan have taken aggressive steps to de-regulate their telecommunications industry, and have promoted competitive services and networks to encourage competition.

Because of their past development leadership, U.S. telecommunications firms face a larger challenge in up-grading their infrastructure than do companies and PTT's in less developed countries. The American telecommunications installed base that must be replaced to install advanced technology is more extensive than elsewhere, and available spectrum for new land mobile services is much less available.

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[23] ibid, pp 26 - 30

[24] Bar, Francois, and Michael Borrus, Information Networks and Competitive Advantage: The Issues for Government Policy and Corporate Strategy, OECD Telecommunications User Group Project Seminar, October 19-20, 1989, Paris

[25] Montgomery, William Page, et. al. The Telecommunications Infrastructure in Perspective, Consumer Federation of America, March 1990 pp 36-42

Assessment of the U.S. telecommunications infrastructure competitive position is a multi-dimensional problem. Network infrastructure development can be divided into three broad categories: switching capacity, transmission capacity, and network intelligence. A modern network capable of providing a full range of services would ideally consist of fiber optic ISDN transmission capacity all the way to individual subscribers, digital switching utilizing common channel signalling, capability of handling business data transmission needs, the intelligence to provide user access to a wide variety of services, and the flexibility to allow the user to reconfigure his system in response to market demands. In addition to wireline offerings, a broad user community would have access to portable services that operate on a regional and nation-wide scale.

No country has yet installed many fiber optic subscriber loops. ISDN deployment, however, gives good indication of the ability to support subscriber service upgrades. Table VI shows ISDN service offerings in several countries. The United States lags a number of countries in introducing even the lowest level of digital service, and the fraction of U.S. lines connected to central offices capable of supporting ISDN is low. By 1992, U.S. lines capable of accessing ISDN will be significantly less that in France, Hong Kong, Japan, and Singapore.[26]

In local exchange digitalization the U.S. network is now competitive with any number of other countries' systems, but at current installation rates, will lag advanced countries by 1994,[27] as will use of common-channel signalling technology.

The United States remains the leader in development and deployment of optical fiber long distance transmission capacity. Over 20,000 miles of fiber optic cable and repeaters have been installed and lit in the U.S. public network by the end of 1989, which is several times that of Japan, the next most developed country. Because of its smaller geographical area, however, Japan has been able to complete its national fiber backbone trunk and is close to linking all its exchanges by fiber.

II. CRITICAL TECHNOLOGIES

As noted above, technology is the driver of the changes now taking place in the telecommunications sector. Technology also holds the keys for solving many of the challenges facing the sector in term of equipment, broader band services and information services. With few exceptions, new discoveries or inventions are not needed to advance our national telecommunications technology to meet foreseen challenges. The technical issues relate primarily to development, manufacture and deployment of equipment using known technology.

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[26] op cit: Davidson, Table 6

[27] op cit: Davidson

Critical telecommunications technologies are in the following areas: User Terminals, Digital Infrastructure, Software, Portable Equipment and Systems, Optical Fiber Technology for Local Service, Broadband Switching, and Database Architecture.

1. User Terminal Technology

Description:

The classic user terminal for wired telecommunications has become the 12-button, Touch-Tone telephone. In the past few years, however, new types of user terminals have arisen to expand the range of options to telephone subscribers. Elements of future user wireline terminal technology include voice recognition and synthesis to eliminate keyboard interfaces, low-cost, bandwidth efficient video displays, new cordless telephone technology, and compatibility with future ISDN service. User terminal technology involves many of the same product design and high volume, high quality, low cost manufacturing factors that characterize consumer electronic products such as audio entertainment and television products. The merger of low-cost personal computer and traditional telephone applications can make possible new types of terminal equipment.

Why is it a Critical Technology?

User terminal technology embodies many of the human interface factors that characterize all user-interface electronic products. Terminals are a critical link in delivering expanded, reliable communications capability to user applications. In addition, for the telecommunications sector, manufacturing unit volume is highest for subscriber equipment and local loop equipment, providing opportunities for use of mass-production skills perfected on other consumer products or developing new ones.

With up-grading of the network infrastructure, user terminals become the focal point in adapting information transmission capability to new applications. New uses of telecommunications in areas such as health-care and education depend upon appropriate terminal products.

U.S. Position Relative to ROW:

The base of suppliers for user equipment has expanded dramatically beyond the traditional telephone equipment manufacturers. Much of the expansion of this base has taken place outside the U.S. as manufacturers of other consumer electronic products have turned their expertise in designing and manufacturing products for broad public consumption.

United States-based manufacturers retain a slight lead in complex technologies such as voice recognition and synthesis, and high performance modems, but lag behind Asian firms in volume manufacturing and special components, such as displays required for many future user terminals. European and Asian firms lead in experience with terminal equipment compatible with the new ISDN standard.

Factors Enhancing U.S. Competitiveness

United States competence in the advanced technologies needed for future user terminals is strong. Basic work in character recognition, voice recognition and synthesis and digital signal processing now leads the world.

U.S. operating companies have installed more digital central offices and interoffice links than any other country by a substantial margin. The size of the American public telecommunications system is so large, however, that the fraction of the U.S. infrastructure that has been converted to digital technology is less than that of many smaller nations.

Factors Detracting from U.S. Competitiveness

United States weakness in several aspects of electronics hardware technology, such as displays, and volume manufacturing skills spills over into the terminal area. Many countries in Europe and Asia still restrict user terminal equipment to approved, locally produced units. As a result, the wireline telecommunications terminal equipment market does not have the global characteristics of other consumer electronics products businesses.

The upgrading of the U.S. telecommunications infrastructure to new technology has been proceeding more slowly than in some other countries. In particular, France and Japan have aggressively pursued digital technology, and France has mounted a highly subsidized program to place 5 M CRT terminals in homes to facilitate access to their experimental Minitel service. The slow pace of U.S. conversion discourages early entry of U.S. user terminal makers into the ISDN and expanded services areas.

Technological Dependencies - Related Technical Issues

Ability to realize the full potential of user terminal performance depends on the rate at which wireline telecommunications facilities are up-graded to include new services such as ISDN, and video capabilities.

2. Digital Infrastructure Technology

Definition

Elements of infrastructure technology include ISDN conversion of each level of the network infrastructure from the terminal interface to long distance transmission. International and national standards and equipment already exist each level of infrastructure for residential and business applications up to 1.544 megabits/second, although details of the U.S. standard differ from those in Europe and Asia. Additional standards for broadband and video applications service have not yet been developed.

Why is this a Critical Technology?

Replacement of the current analog subscriber loop by broader band digital service is the key to realizing the full potential of wireline telecommunications for improving business efficiency and to providing growth opportunities for telecommunication services. With digitization comes the ability to commingle all types of information in a single system and to readily translate between them.

The current analog telephone system is incapable of meeting the needs of an increasing load of digital data transmission. Furthermore the demands for increased data transmission rates from both business and residential computer and facsimile users will soon exhaust the bandwidth of analog voice-grade lines. Digital infrastructure technology combining both voice and data on the same switched network has been agreed upon.

U.S. Position with Respect to the Rest of the World

In the United States, ISDN service is now available only on a limited basis to commercial subscribers, well behind the service offerings in France, the U.K., Japan and Singapore. Similarly, conversion of U.S. central office switches to digital technology, a prerequisite to local ISDN availability, lags behind that of a number of other advanced countries.

Factors Enhancing U.S. Competitiveness

U.S. operating companies can and do buy equipment from suppliers anywhere in the world. They have access to the same level of equipment technology available anywhere. No fundamental technological developments are required to deploy ISDN technology, and U.S. equipment producers can be ready to ship ISDN network equipment on short notice.

Factors Detracting from U.S. Competitiveness

Deployment of ISDN technology required to up-grade the United States telecommunication network requires replacement of already installed analog technology. Long depreciation lifetimes and regulatory rate of return restrictions have delayed the upgrading of this technology.

In addition, differences between the U.S. T1 ISDN standard and that adopted for use elsewhere in the world means that U.S. primary service equipment must be incompatible with that made for other countries.

3. Software

Definition

Stored program software is the embedded set of instructions that govern the intelligent performance of the telecommunications network. Future networks will require a new software architecture, in which boundaries between functions can be established and used to allow developers to independently introduce new features through more modular programs. Well defined interfaces must ensure compatibility and interoperability between different vendors' programs. The approach will not only enable reduce the complexity associated with the design of new features, it will also enable network provider and users to more quickly and economically introduce new services and applications.[28]

Why is it a Critical Technology?

The complexity and interactive nature of the modern telecommunications network makes the entire system vulnerable to even tiny errors in concept or coding. The software failure that led to the disabling of a large part of the AT&T long-distance network on January 15, 1990 is a good demonstration of system-wide vulnerability to software errors.

> In the future, software will play and even greater role in telecommunications. Research in artificial intelligence, and the development of expert systems could result in improved operations and maintenance functions and more efficient trouble shooting and fault isolation. ... software programs could be installed to manage usage, dynamically routing traffic to maintain high overall performance and accommodate transient load conditions. Other future applications ... might include software driven interfaces, voice recognition, and more dynamic user-network interactions.[29]

U.S. Position with Respect to the Rest of the World

As in other software technology areas, United States telecommunications suppliers are regarded as retaining a strong leadership position with respect to foreign competitors. However, foreign manufacturers do offer telephone switches, transmission equipment and customer premises equipment whose features are equal, or in some cases superior, to those offered by domestic U.S. suppliers. Since many of these features are driven by software -- and the products work -- it is hard to argue whether the United States has a clear lead.

Factors Enhancing U.S. Competitiveness

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[28] ibid, p. 21

[29] Bell Communications Research, Bellcore's Vision of the Future, document filed in response to NTIA Notice of Inquiry, April 9,1990

Overall U.S. software strength reinforces our competence in the telecommunications software field. Many of the problems noted above result from the extremely complex nature of the overall U.S. network -- a problem no other country has seen on a comparable scale.

Factors Detracting from U.S. Competitiveness

Many aspects of software coding and testing remain labor intensive. The relative cost of labor in the U.S. versus other, emerging industrial nations places U.S. software vendors at a disadvantage.

4. Portable Equipment and Systems Technology

Definition

Portable telecommunications technology includes a full range of wireless equipment and services that many or many not interact with the telecommunications network.

Critical elements of wireless communications technology include system developments to allow efficient spectrum usage by a large number of users, digital signal processor technology to facilitate development of flexible, rugged multipurpose transmitters and receivers, and unique hardware technologies, such as high capacity, rechargeable batteries and low power displays.

The evolution of low-cost, high function integrated circuit electronics made cellular telephone, a complex system requiring sophisticated electronics in both infrastructure and subscriber instrument, practical. The spectrum "reuse" concepts employed in the cellular system, as well as spread-spectrum technology and use of high frequency portions of the microwave spectrum. make much more efficient use of limited spectrum resources than possible with traditional radio services. These and other new radiotelephone systems, such as micro-cellular, make it possible to support many more simultaneous users than previously possible.

Why is this a Critical Technology?

User demand for tether-free communications has been demonstrated by the rapid growth of cellular telephone, trunked radio and paging services.

Wireless technology is important, not only because of the possibility of a large nascent consumer market, but also because wireless communications can be an influential factor in improving productivity and reducing costs, especially in service sector applications.

In many applications, such as offices and residences, wiring costs dominate the installation and maintenance expenses of telecommunications service. Wireless solutions offer the possibility of significantly reducing deployment investment.

U.S. Position with respect to the Rest of the World

The United States has been the world leader in development and use of land mobile radio services. U.S. manufacturers have led the rest of the world in devising imaginative system, hardware and software designs that open new possibilities for radio communication. Cellular telephone development has recently accelerated in Europe, however, and the adoption of a new digital cellular standard for Europe enhances the position of some already strong European telephone manufacturers in this area.

Factors Enhancing U.S. Competitiveness

U.S. strength in wireless system and component technologies. Extensive U.S. experience with existing land mobile services.

U.S. manufacturers have been strong competitors in foreign markets for wireless infrastructure equipment, such as paging and cellular fixed installations. Technology developed at home has been effectively leveraged as the rest of the world has begun late deployment of wireless telecommunications.

Factors Detracting from U.S. Competitiveness

The radio spectrum in the United States is much more crowded than in other countries, especially because of the large, under-utilized UHF TV allocation. Consequently, without reallocation of existing services, development of new wireless applications requiring new spectrum is much more difficult here than elsewhere. Lack of available spectrum has been a major factor in slowing development of new applications for wireless office and land mobile users.

The United States has lagged Europe in adoption of the next-generation standard for cellular telecommunications - digital cellular. The European head start in this area gives European equipment manufacturers lead time in designing and refining next-generation digital cellular products.

As wireless subscriber equipment such as pagers and cellular telephones becomes a consumer item, the consumer product design and manufacturing strengths of Asian electronics companies become an important factor. U.S. manufacturers have limited collateral consumer electronics manufacturing experience to build on.

5. Optical Fiber Technology for Local Service

Definition

The fiber technology called for in the subscriber loop application must be capable of transmitting the full video, digital and voice services over distances of several thousand yards. The cost must be less than existing technology, and the quality and reliable extremely high, consistent with exist local loop standards.

Why is this Critical Technology?

Local loop fiber is critical if the market demand and regulatory environment promote residential deployment of broadcast video services over the switched telecommunications network. Neither twisted pair wire nor wireless technology has sufficient bandwidth to support this level of service.

U.S. Position with Respect to the Rest of the World

U.S. telecommunications manufacturers have developed both fiber and optoelectronics interface technology capable of meeting the technical requirements of the local loop application. In fact, the U.S, technology embodied in existing long distance trunks goes well beyond that required for the local loop application. The key area of concern is cost to manufacture the optoelectronic terminations for the short-haul fiber at a sufficiently low cost to be competitive in local loop applications. In this area, the Japanese have the advantage of mass-production experience with reliable, long-life lasers for consumer applications such as compact discs. No U.S. manufacturer has comparable volume manufacturing experience.

Factors Enhancing U.S. Competitiveness

U.S. telecommunications equipment manufacturers (particularly AT&T Technologies) has extensive experience in producing equipment for local loop applications. They also have access to some of the world's best solid state optoelectronics technology.

Factors Detracting from U.S. Competitiveness

The Japanese have an accumulated lead in solid state lasers for consumer electronics applications. They have demonstrated their willingness to invest in technology for long-term pay-off, and to absorb large, early start-up costs.

6. Broadband Switching

Broadband switching is one of the few telecommunications hardware areas requiring extensive new developments. Broadband switching is not an immediate problem in deploying service contemplated in the current upgrade to ISDN or fiber optic technology, but will be a possible bottleneck for services with video bandwidths.

Definition

Broadband switching is the means by which the central office switch directs optical signals from their sources to their intended destinations. Current technology is quite adequate to handle existing services, however the incorporation of switched video signals into the PSTN would require switching technology have much broader bandwidth capability. Such broadband technology entails the direct switching of light-borne signals.

Why is this a Critical Technology?

Broadband switching is one of the few telecommunications hardware areas requiring extensive new developments. Broadband switching is not an immediate problem in deploying service contemplated in the current upgrade to ISDN or fiber optic technology, but will be a possible bottleneck for services with video bandwidth. Broadband switching is critical for possible future telecommunications services. This is not so much a concern for the next decade, as it is an issue for the early 21st Century as data and video transmission rates exceed those feasible with today's widely available systems.

In addition, successful development of optical switching for telephone applications may provide a stepping stone to optical computing technology.

U.S. Position with respect to the Rest of the World

Within the United States, AT&T Bell Laboratories probably has the most advanced broadband switching technology, however Fujitsu in Japan and Bell Northern are also working hard on the problem. Current assessment is that the United States still has a leadership position.

Factors Enhancing U.S. Competitiveness

AT&T Bell Laboratories strong position in leadership telecommunications technology. It has continued its work in basic technologies to support broadband switch development.

Factors Detracting from U.S. Competitiveness

The ability of the current AT&T organization to maintain its commitment to such long-term technology developments.

7. Database Architecture

Definition

Database architecture technology deals with the organization of stored data for later access. The organization strongly affects ease and speed of information retrieval, and the characteristics and cost of the equipment needed to contain the data.

Why is this a Critical Technology?

More and more telecommunication services operate by means of accessing information stored in databases. In today's network, much of the data needed to route and complete calls reside in switch memory. In the future, the level of data and information exchange needed to establish the complex interactions needed to deliver advanced services will be many time larger than required today.[30] The size and structure of databases future networks is therefore of concern. Databases are at the heart of advance central office switching technology required to support advanced telecommunications services. As intelligence is dispersed throughout the network, requirements that databases include a large range of information to deal with a wider range of network operating modes increase.

U.S. Position with respect to the Rest of the World

Again, because of the relative complexity of the U.S. network with respect to those in place elsewhere in the world, U.S. telecommunications operators and equipment manufacturers have more experience with this problem, which is strongly system complexity-driven. Hence the United States leads in this area. Factors enhancing and detracting from U.S. competitiveness in database architecture are similar to those for software.

Factors Enhancing U.S. Competitiveness

United States strength in computer software, architecture and systems complements database architecture for telecommunications systems. Much of this development effort is carried on within universities, as well as in telecommunications firms, and is the focus of the efforts of a very active technical community.

Factors Detracting from U.S. Competitivness

Database architecture for telecommunication systems is similar to that for computer systems. Work underway, primarily in Japan, to create new generations of computer systems with massive database requirements, such as those needed for contextual language translation, have significantly increased their effort in this area. While United States competence in database architecture for telecommunications systems now leads the world, efforts by other countries to develop related technologies must be carefully monitored.

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[30] ibid: p. 22

III. Policy Issues

The telecommunications industry is strongly affected by numerous policy issues at the Federal, state and local level. What follows is a short list of some of the more important issues that must be addressed in determining the future of the sector.

Regulation

The telecommunications business is highly regulated at the federal, state and local levels. The Communications Act of 1934, which governs United States telecommunications policy, is somewhat ambiguous in allocating responsibility between the States and the Federal Government. Regulatory jurisdictions often overlap, and frequently it is impossible to satisfy the requirements of all regulators. In spite of the "de-regulation" of parts of the telecommunications industry (e.g., opening of long-distance competition, and the break-up of AT&T) many aspects of the industry remain tightly controlled. Service charges, equipment depreciation rates, spectrum usage, and the requirement for universal service and equitable access all are set by one or more regulatory bodies. Policies of these bodies bear directly on the ability and desire of telecommunications carriers to invest in up-grading the infrastructure to offer expanded services.

Modified Final Judgement

The settlement of the antitrust suit brought by the U.S. against AT&T is embodied in the Modified Final Judgement (MFJ).[31] The MFJ established the companies resulting from the break up (the new AT&T and the RBOC's) and also specified restrictions on RBOC business activities. These restrictions include prohibitions against manufacturing, provision of long distance services, and provision of information services.

The RBOC's have responded to a Notice of Inquiry by the National Telecommunications and Information Administration (NTIA) by requesting relief from these line of business restrictions and suggesting changes in regulatory policy.[32] Other respondents have indicated a desire to retain the restrictions.[33] The outcome of this action could have a substantial effect on the future structure of the telecommunications industry.

Standards

Interoperability is key to the successful functioning of the telecommunications network -- interface and end-to-end service and performance standards are essential to achieving nationwide compatibility. Standards have long lain at the heart of infrastructure system and equipment design. Three standards issues are now critical:

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[31] op cit: U.S. vs. Western Electric Co. Inc., et. al.

[32] Reference to documents filed in response to the NTIA Notice of Inquiry

[33] Montgomery et al.

Existing standards generally relate to physical and electrical connections and signalling protocols. Increasingly, however, standards that allow applications-level compatibility between business users are becoming important in facilitating trade between vendors and customers or parties to other transactions. Little effort to date has gone into defining what such standards might be.

ISDN has been formally agreed to as the world standards framework for digital telecommunications services within the public network. Similar standards for use in private networks to insure interoperability. As long as a single organization (such as a company or a network service provider) is the exclusive user of the network, interoperability is not a problem. When several organizations (such as vendors and customers) become involved interoperability must be confronted.

Future implementation of broadband digital services cannot go forward without agreement on a broadband version of ISDN (BISDN). Work on this group of standards is proceeding very slowly.

R&D Base

AT&T Bell Laboratories has achieved a remarkable record in discovery and invention of basic technology for the communications and electronics businesses. Before the breakup of the system, Bell Labs was, in essence, our premier national laboratory in these fields, supported by an invisible tax on most of the nation's telephone bills. Results developed within its laboratories were widely available to industry under very liberal licensing terms and conditions.

Other large corporate laboratories, such as those at RCA, ITT, GTE and GE, have been reorganized or scaled down to the point where their role in development of the national technical base is substantially diminished.

With the dissolution of the vertically integrated corporate R&D structures, serious concern has been voiced that the nation has lost an important part of its industrial technology development structure. Increased emphasis on the proprietary nature of generic technology developments and restructuring and reduction of efforts not directly supporting current businesses have left a hole in the technology fabric of the country that has not been replaced.

Intellectual Property Rights and Standards

Conflict is developing between private intellectual property rights and need for universal operating standards. As indicated above, standards are critical to an effective telecommunications system. However, many standards incorporate patented systems inventions by private firms that are deemed the most effective solutions to technical problems addressed by standards bodies.

Increasingly, in both Europe and Asia, national standards bodies have begun to insist that patents covering official standards be licensed free of charge to equipment and service providers incorporating the standard. In essence, such a policy can amount to seizure of intellectual property.

While access to technology incorporated in standards is essential to their acceptance, insistence that licenses be granted free of charge, or for unreasonably low royalty rates is a strong disincentive to continued research and development in areas likely to be covered by future standards. At present, the U.S. has no policy on how to respond to this intellectual policy issue.

Spectrum

Radio spectrum is a fixed, non-renewable resource. As telecommunications technology advances, particularly in the United States, where the spectrum is heavily used, availability of frequencies becomes a limiting factor in the ability to deploy new services in the wireless area. The U.S. process for frequency allocation is extremely slow (compared to that of other countries). For example, deployment of cellular telephone was delayed ten years by the frequency allocation and licensing process.

Availability of spectrum for new services depends, in part, upon the ability to re-allocate existing services (especially the U.S. UHF television allocation), and if necessary, move them off the air and onto the wireline network.

World spectrum allocations are reviewed infrequently, and the next meeting is to held in 1992. The U.S. is behind European and Asian countries in establishing its strategy for this negotiation that will have a strong effect on the ability to provide future advanced telecommunications services.

Access to Foreign Equipment Markets

Historically, telecommunications has been regarded by many nations as a national monopoly, both in provision of services and equipment supply. In the past 5 to 7 years, however, some countries have liberalized their telecommunications establishments (especially the U.S., U.K. and Japan) and have sought equipment abroad. A number of nations still hold to the idea of a closely held service and equipment base (such as France and West Germany) and have sought to use their home markets as a springboard for an equipment export industry.

As in other industries, market access restrictions are regarded as unfair trade restrictions, and can become an element in U.S. trade policy.

FIGURE 1

Residential Telephone Penetration

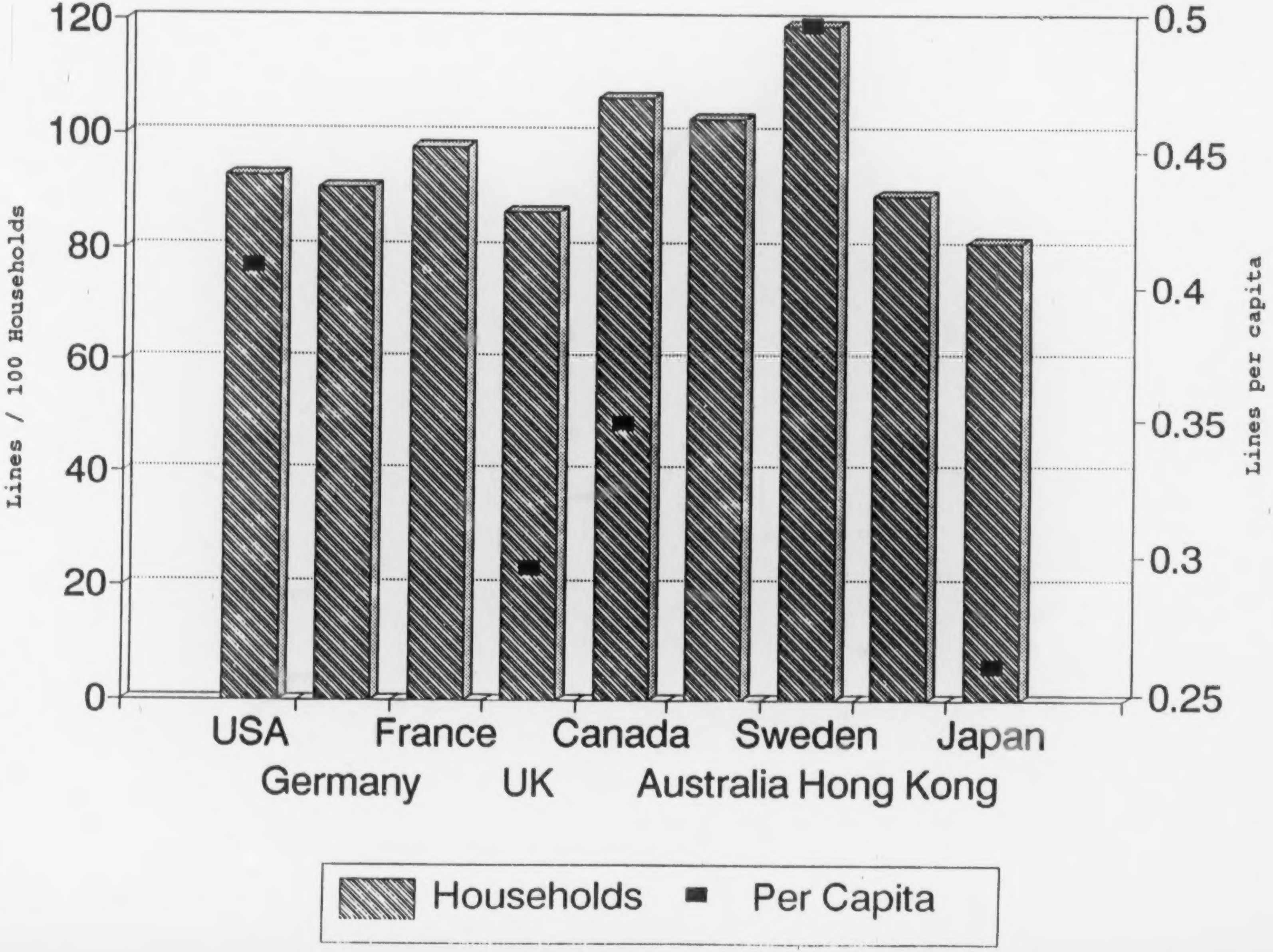

FIGURE 2
Global Telephone Equipment Sales

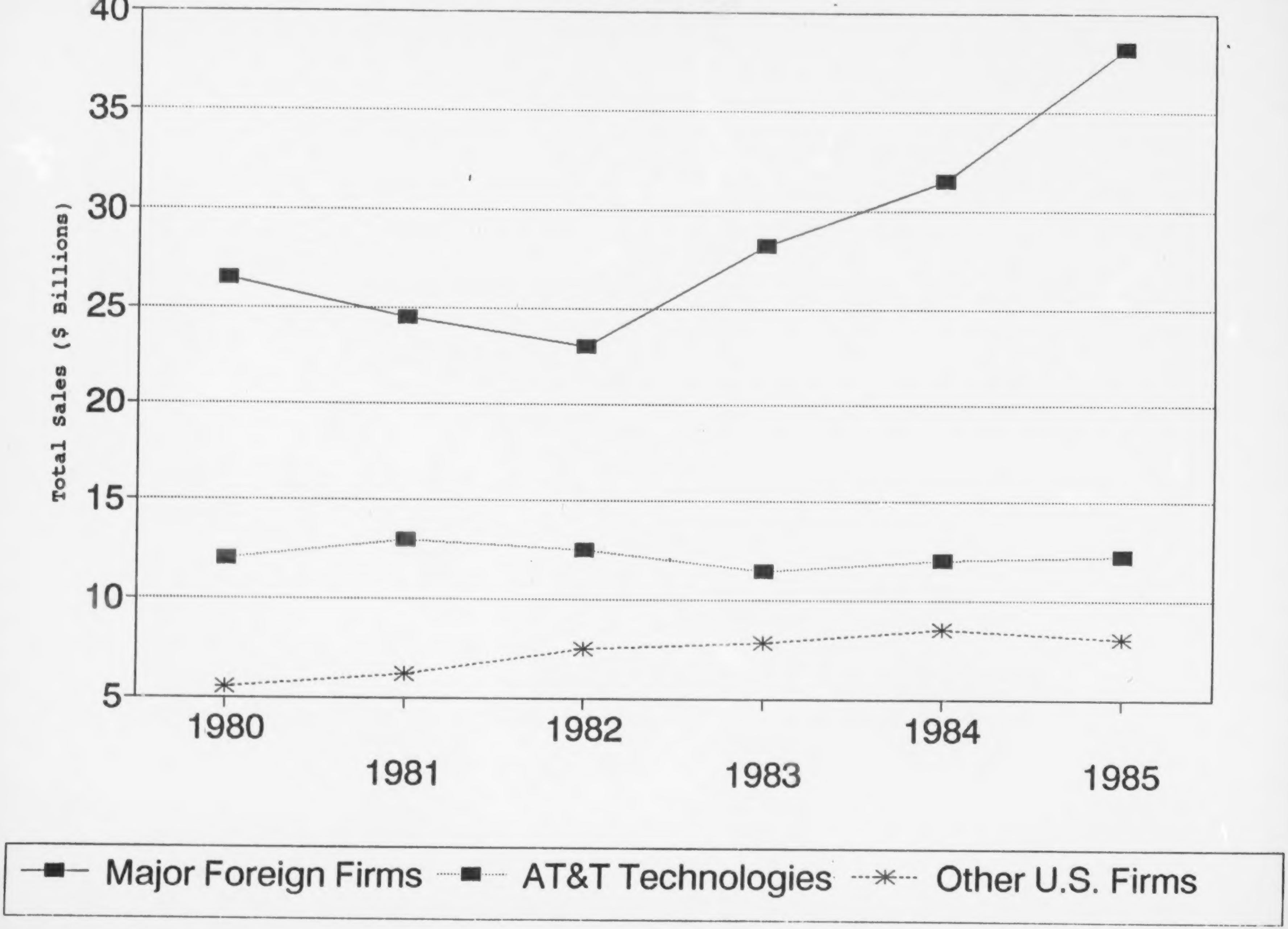

FIGURE 3
U.S. Trade in Telephone Equipment

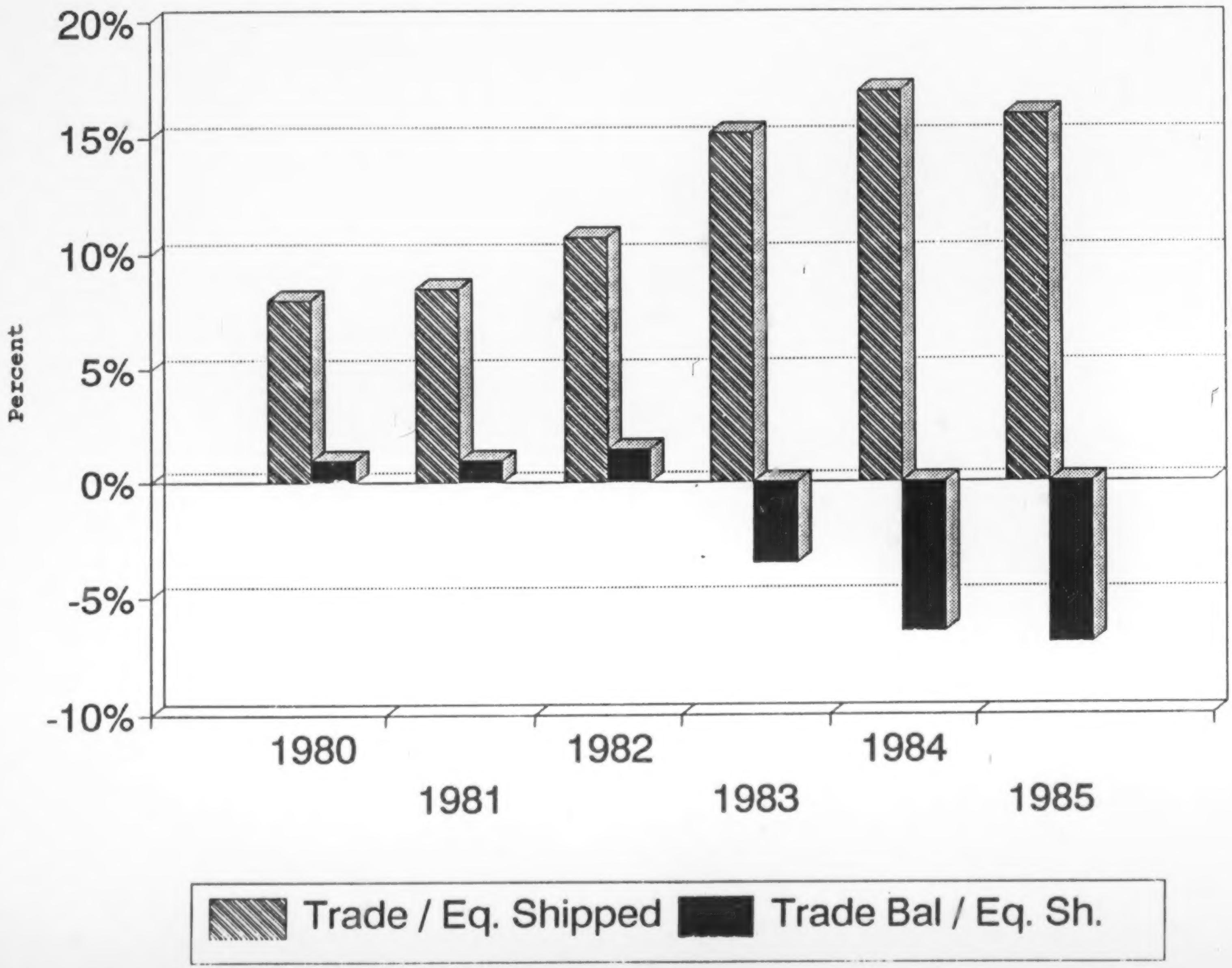

FIGURE 4

U.S. Trade Balance in Telephone Equip.
By Type of Equipment

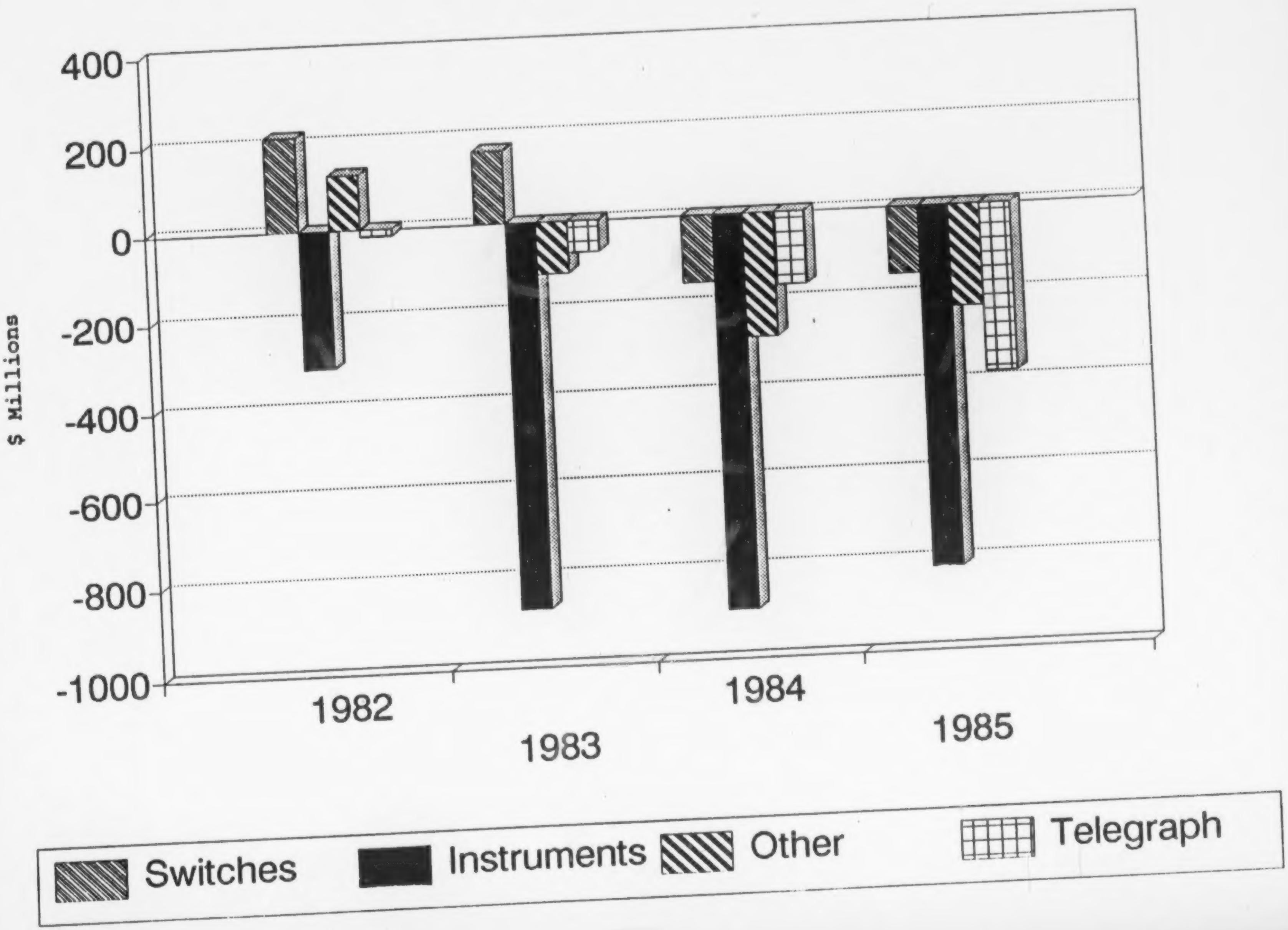

FIGURE 5
Telecommunications Market

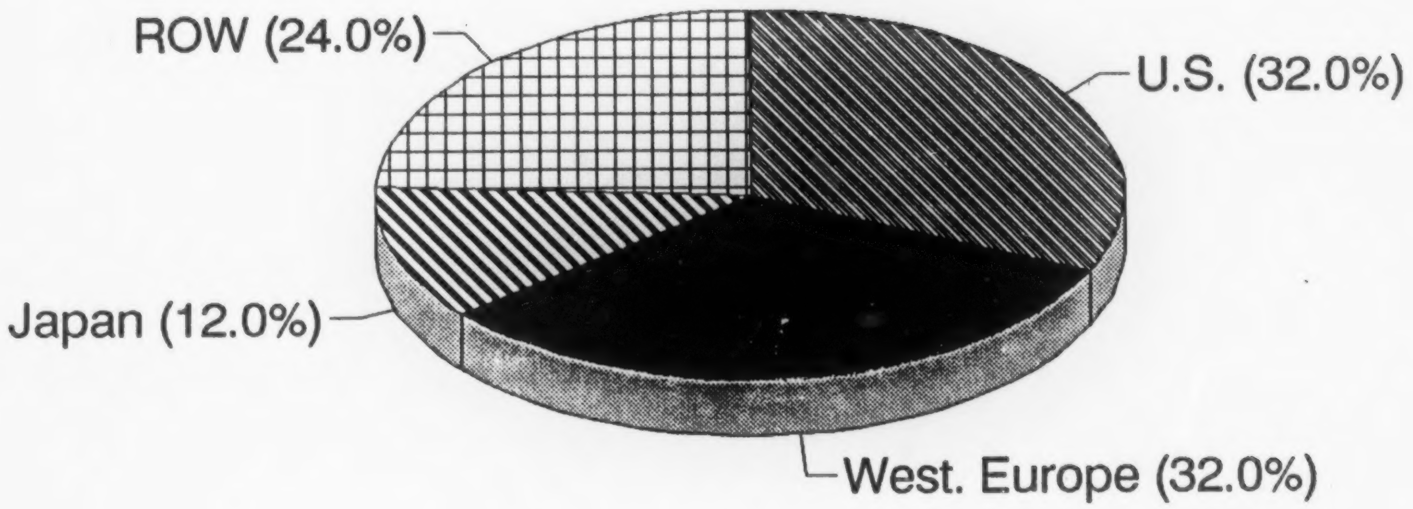

Table I: Major Types of Wireline Competitors

Local Exchange Carriers (including RBOC's)

Long Distance (Inter-exchange) Carriers (AT&T, MCI, Sprint, ...)

International Carriers (AT&T, Cable & Wireless, KDD, ...)

PTT's (aboard)

Corporate Communications Departments

Private Network Operators (Sears, Southern Pacific, ARCO, ...)

Computer Data Networks (Dialcom, Tymnet, ARPANET, NSFNET, Internet, ...)

Cable TV Companies

Alternate Service Providers (N.Y. Teleport, ...)

Table II: Major Wireless Telecommunications Competitors

Independent Cellular Telephone Operators

Wireline Cellular Telephone Operators

Airfone

Special Mobile Radio Services (SMRS)

Radio Common Carriers (RCC's)

Mobile Satellite Services

Table III: Major Players in the Value-Added Services Market

ADP (Alarm Services)
AT&T
RBOC's
Boeing Computer Services
Dialcom (on-line data services)
Cable and Wireless
Control Data Corporation
Compuserve
EDS (General Motors)
GEIS (General Electric)
IBM Information Network
INET (Bell Canada)
Infonet (Computer Sciences Corporation)
Worldnet (ITT)
Cylix (RCA/GE)
Telenet (U.S. Sprint)
Tymnet (British Telecom)
United Telecom
Wangpac (Wang)
Easylink (Western Union)

Table IV: Telecommunications Equipment Suppliers

Traditional Common Carrier Telecommunications Equipment Providers (AT&T Technologies, Northern Telecom, GTE, L.M. Ericsson, ...)

Customer Premises Equipment Makers (AT&T, Northern Telecom, Rolm, ...)

Consumer Electronics Suppliers (terminal equipment makers) (American Telecom, AT&T, Sony, Matsushita, ...)

Radio Communications Suppliers (Motorola, GE, L. M. Ericsson, NEC, ...)

Computer Equipment Manufacturers (DEC, IBM, Apple, ...)

Modem Suppliers (Hayes, UDS, Codex, ...)

Special Equipment Suppliers (aerospace companies, test equipment manufacturers, ...)

Independent Software Providers

Table 5-4—Top 50 U.S. Communication Users

Rank	Company	Primary business	Employees (in thousands)	Revenues ($billions)
1.	General Motors Corp., Detroit, MI	Automotive	813	101.78
2.	General Electric Co., Fairfield, CT	Manufacturing	302	40.52
3.	Citicorp/Citibank N.A., New York, NY	Banking	90	119.56
4.	IBM, Armonk, NY	Computer	389	54.22
5.	American Express Co., New York, NY	Finance	84	17.77
6.	Westinghouse Electric Corp., Pittsburgh, PA	Manufacturing	112	10.68
7.	McDonnell Douglas Corp., St. Louis, MO	Aerospace	112	13.34
8.	Sears Roebuck and Co., Chicago, IL	Retail	500	48.44
9.	Ford Motor Co., Dearborn, MI	Automotive	350	71.64
10.	Boeing Co., Seattle, WA	Aerospace	136	15.36
11.	Rockwell International Corp., El Segundo, CA	Manufacturing	116	12.12
12.	Prudential Insurance Co. of America, Newark, NJ	Insurance	66	14.05
13.	Lockheed Corp., Calabasas, CA	Aerospace	99	11.32
14.	Xerox Corp., Stamford, CT	Manufacturing	99	15.13
15.	United Technologies Corp., Hartford, CT	Manufacturing	190	17.17
16.	ITT Corp., New York, NY	Manufacturing	120	19.53
17.	Unisys Corp., Blue Bell, PA	Computer	93	9.71
18.	Union Carbide Corp., Danbury, CT	Manufacturing	43	6.91
19.	Texas Air Corp., Houston, TX	Airline	70	8.46
20.	United Parcel Service of America Inc., Greenwich, CT	Transportation	192	9.68
21.	BankAmerica Corp., San Francisco, CA	Banking	85	76.29
22.	E.I. du Pont de Nemours & Co., Wilmington, DE	Manufacturing	140	30.47
23.	Raytheon Co., Lexington, MA	Manufacturing	77	7.66
24.	Allied Signal Inc., Morristown, NJ	Manufacturing	115	11.12
25.	Caterpillar Inc., Peoria, IL	Manufacturing	54	8.18
26.	Chase Manhattan Corp., New York, NY	Banking	42	68.58
27.	J.P. Morgan & Co. Inc., New York, NY	Banking	164	3.99
28.	General Dynamics Corp., St. Louis, MO	Aerospace	105	9.34
29.	Chrysler Corp., Highland Park, MI	Automotive	141	26.28
30.	USX Corp., Pittsburgh, PA	Manufacturing	54	13.90
31.	First Interstate Bancorp., Los Angeles, CA	Banking	36	37.57
32.	Honeywell Inc., Minneapolis, MN	Manufacturing	79	6.68
33.	Digital Equipment Corp., Maynard, MA	Computer	111	9.39
34.	AMR Corp., Dallas/Ft. Worth, TX	Airline	65	7.20
35.	Eastman Kodak Co., Rochester, NY	Manufacturing	124	13.31
36.	J.C. Penney Co. Inc., Dallas, TX	Retail	181	15.33
37.	Pepsico Inc., Purchase, NY	Manufacturing	225	11.49
38.	Metropolitan Life Insurance Co., New York, NY	Insurance	36	13.96
39.	Chemical New York Corp., New York, NY	Banking	29	55.51
40.	Amoco Corp., Chicago, IL	Oil	47	20.17
41.	May Department Stores Co., St. Louis, MO	Retail	143	10.31
42.	Minnesota Mining & Mfg. Co. (3M), St. Paul, MN	Manufacturing	82	9.43
43.	Merrill Lynch & Co. Inc., New York, NY	Finance	43	10.87
44.	Texaco Inc., White Plains, NY	Oil	50	34.37
45.	Cigna Corp., Philadelphia, PA	Insurance	48	16.91
46.	UAL Corp., Chicago, IL	Airline	66	8.29
47.	Federal Express Corp., Memphis, TN	Transportation	41	3.20
48.	R.H. Macy & Co. Inc., New York, NY	Retail	54	5.21
49.	First Union Corp., Charlotte, NC	Banking	20	17.43
50.	Mobil Corp., New York, NY	Oil	121	56.72

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Table VI: Percent of Lines Equipped with ISDN Capacity

Country	1990	1992	1994
France		100%	100%
Hong Kong		100%	
Japan	76%	87%	100%
Singapore	100%	100%	100%
United States	5%	19%	24%

ABOUT THE PROJECT

This research paper is part of an in-depth, two-year study to assess whether U.S. national technology priorities meet the needs of American industry in the global economy. The final report of the project, Gaining New Ground: Technology Priorities for America's Future, was published in March 1991.

The project had three fundamental objectives: 1) to identify, on a sector-by-sector basis, the critical technologies that will drive performance in key sectors of the economy in the 1990s, 2) to assess the strengths and weakness of U.S. industry and the U.S. policy environment with respect to developing these technologies and 3) to use this information to develop national technology priorities to guide U.S. public policy and private-sector management related to technology.

This research paper is one of nine studies of technology intensive sectors of U.S. industry. Each study evaluated the sector's approach to technology, its competitive position, and the key technologies driving its performance. These studies served as a basis for deliberations by the Council's technology advisory committee and for the findings and recommendations in the final report.

Each of the nine research papers was reviewed by the technology advisory committee and by leading technology experts, business executives, university professors and officials, labor leaders, and industry associations. Although these groups all provided valuable input, they do not necessarily agree with everything in the studies.

These research papers were not reviewed or approved by the Executive Committee of the Council on Competitiveness. Consequently, the views expressed in these profiles do not represent the official position of the Executive Committee of the Council. The Council's consensus findings and recommendations are contained in the final report, Gaining New Ground: Technology Priorities for America's Future.

The Council on Competitiveness would like to thank William G. Howard for preparing this profile.

The Council would like to thank Pfizer Inc. and NMTBA/The Association for Manufacturing Technology for their assistance in publishing the profiles.

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*Dr. Spencer served on the Committee in his role as Vice President, Science and Technology, Xerox Corporation, prior to his appointment to Sematech.

ABOUT THE COUNCIL

Founded in 1986, the Council on Competitiveness is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor who have joined together to pursue a single overriding goal: to improve the ability of American companies and workers to compete more effectively in world markets while raising the standard of living at home.

To build consensus within the public- and private-sectors on the actions needed to help Americans compete, the Council pursues a three-part agenda: increase public awareness of the breadth and severity of America's economic problems; mobilize the political will required to set the United States on a positive economic course; and assist in the development of specific public policies and private-sector initiatives. To that end, the Council combines action and analysis in four issue areas: fiscal policy, science and technology, international economics and trade, and human resources.

The Council is governed by an executive committee and draws on the resources of its national affiliates -- more than two dozen trade associations, professional societies and research organizations -- to help analyze issues and develop consensus. The Council is privately supported through contributions from its members, foundations and other granting institutions.

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